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Journal of the American Society of Agronomy

VOLUME 40 JANUARY, 1948 NUMBER 1

Contents

Subscription $7.50 per year in United States and Canada; $8.00 foreign.
Single Copies 75 cents.

Published Monthly by the Society

Journal American Society of Agronomy

ISSUED ON THE 15TH OF EACH MONTH
AT GENEVA, N. Y.

Address all manuscripts and correspondence regarding manuscripts, proofs, etc., to the Editor at P. O. Box 353, Geneva, N. Y.

For advertising rates and information about advertising in the JOURNAL, consult the Macfarland Company, 289 Fourth Avenue, New York 10, N. Y., advertising representatives of the Society.

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Entered as second class matter March 30, 1922, at the post office at Geneva, N. Y., U. S. A., for mailing at the special rate of postage provided in section 1103, Act of Oct. 3, 1917

Made in the United States of America

American Society of Agronomy JOURNAL

VOLUME 40 FEBRUARY, 1948 NUMBER 2

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Made in the United States of America

American JOURNAL Society of Agronomy

VOLUME 40 MARCH, 1948 NUMBER 3

Annual Meeting, Fort Collins, Colorado, August 24 to 27, Inclusive

Contents

Subscription $7.50 per year in United States and Canada; $8.00 foreign.
Single Copies 75 cents.

Published Monthly by the Society

American Society of Agronomy JOURNAL

VOLUME 40 APRIL, 1948 NUMBER 4

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Single Copies 75 cents.

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American Journal of the Society of Agronomy

VOLUME 40 MAY, 1948 NUMBER 5

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Journal American Society of Agronomy

VOLUME 40 JUNE, 1948 NUMBER 6

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Single Copies 75 cents.

Published Monthly by the Society

American Journal of the Society of Agronomy

Vol. 40 January, 1948 No. 1

The Phosphorus Cycle and Soil Fertility[1]

W. H. Pierre[2]

FOUR years ago in this same room we listened to an able presentation of the need of using more phosphate fertilizers as a means of greatly increasing our food production during the world crisis (36).[3] Since that time we have increased our annual consumption of phosphate fertilizers by over 30%. Yet the role of phosphorus in the national and world problem of food production and adequate nutrition has not been diminished. Phosphorus is so basic to the whole problem of crop production that probably no other subject in the field of soil fertility has received more attention through the years than the phosphorus problem in its various soil-plant and soil-animal relationships. And it probably will continue to challenge the best efforts of investigators for many years.

I have chosen as the subject of my talk this evening, "The Phosphorus Cycle and Soil Fertility". It is an ambitious subject—one that if treated fully would fill a good-sized book—for all phases of the soil phosphorus problem are related directly or indirectly to the phosphorus cycle. I can assure you immediately, however, that it is not my intention to cover this subject in all its implications. This subject is one in which I have long been interested; I chose this title because it emphasizes a viewpoint that is sometimes missed in the consideration of soil problems. The term "cycle" implies that we are dealing with a dynamic system—a system where soil, plant, and microorganism all play important roles. Moreover, it implies an over-all rather than a key-hole view of the problem. As a field of inquiry develops, it is necessary to specialize on narrow phases of a problem. But in so doing, we sometimes neglect the broader relationships, a full understanding of which is so often necessary for a solution of the immediate problem. While this may not be any more true of phosphorus than of many other agronomic problem, I believe you will agree that there are serious gaps in our knowledge, which become evident as we examine the phosphorus cycle.

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[1]Presidential address presented at the annual meeting of the Society, Cincinnati, Ohio, November 19, 1947. Journal Paper No. J-1502 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 617.

[2]Professor of Soils and Head, Department of Agronomy, Iowa State College, Ames, Iowa.

[3]Figures in parenthesis refer to "Literature Cited", p. 12.

At any rate, I would like to sketch some of the important and possibly less generally recognized phases of this cycle with you this evening, particularly the organic or biological phase.

A GENERAL VIEW

In the simplest sense, we can think of the phosphorus cycle as the absorption of soil phosphorus by plants and the return of phosphorus to the soil through plant and animal residues. More accurately, however, we are concerned (a) with all the chemical and biological changes that are continually taking place in the various phosphorus compounds of the soil, (b) with the transformations that occur as phosphorus is absorbed and utilized by plants and by soil microorganisms, and (c) with the reconversion of the organic phosphorus of plant and microbial residues to simpler forms through microbial processes or enzyme action.

In many respects, the phosphorus cycle may be likened to the nitrogen cycle. Phosphorus like nitrogen is found in organic and inorganic forms in soils and in plants. The mineralization of both organic phosphorus and nitrogen compounds contributes to the nutrient supply of plants. In the nitrogen cycle the auxiliary source of supply is the nitrogen of the air, brought into the cycle by the processes of symbiotic and nonsymbiotic nitrogen fixation. In the phosphorus cycle, the auxiliary supply comes from the store of unweathered phosphorus minerals of both surface and subsoil, brought into the biological part of the cycle through absorption by plant roots and soil microorganisms. Even this supply of phosphate minerals is not static in terms of the long-time cycle of erosion and deposition.

Next to nitrogen, phosphorus is the most abundant nutrient element contained in microorganisms, making up as much as two per cent of their dry weight. Largely for that reason, phosphorus is, next to nitrogen, the most important nutrient element in soil organic matter. And phosphorus availability like nitrogen availability is closely linked to the activity of soil microorganisms.

CLASSES OF PHOSPHORUS COMPOUNDS IN SOILS

The phosphorus compounds of soils can be grouped into three general classes: (a) The inorganic compounds in which the phosphorus is combined largely with calcium, magnesium, iron and aluminum and with clay minerals, (b) the organic compounds present in plant and animal residues and products of microbial synthesis, and (c) the organic and inorganic phosphorus compounds in the cells of living matter, which in a sense serve as the connecting link between the other two general classes of compounds.

INORGANIC PHOSPHORUS COMPOUNDS

Of these three classes, the inorganic phosphate compounds have received by far the largest amount of attention. In many soils, particularly in the lower horizons, a portion of the phosphorus still exists as fluorapatite, the mineral from which practically all the phosphorus in soils was derived. This mineral is very resistant to weathering and

has been petrographically identified in the silt and sand fractions of many soils, including some that are highly weathered (16). In the processes of weathering and soil development part of the phosphorus, released from apatite, forms secondary compounds of varying solubility; some is absorbed by plants and microorganisms to be converted to organic combinations and later, in part, returned to the soil in the accumulating organic matter.

Although most of the soil inorganic phosphorus compounds cannot be isolated and positively identified, considerable indirect evidence is available as to the type of compounds present (14, 32). The calcium phosphates constitute a series, ranging from the relatively soluble mono and di-calcium phosphates, which are present only in small amounts, to relatively insoluble hydroxyapatite and fluorapatite. The iron and aluminum phosphates may also vary widely in solubility depending on the amounts of phosphorus present in the compounds. In soils, however, they probably exist largely as basic compounds such as in the minerals dufrenite and wavellite, which are very insoluble except under neutral or alkaline conditions. There is also evidence that some inorganic phosphorus in soils may be combined with clay minerals (11,17). Any clay-lattice phosphorus present would be only slightly available to plants, whereas that which may exist in hydroxyl positions (7, 34) or as "cation-exchange phosphate" (2) on the surface of clay minerals would have a fairly high availability.

In general, solubility studies have shown that the inorganic phosphates of iron and aluminum tend to accumulate in acid soils whereas calcium phosphates are predominant in neutral or alkaline soils (11, 32). A pH of about 6.5 to 7.0 is desirable from the standpoint of phosphorus availability because this range is above the pH of minimum solubility of iron and aluminum phosphates and below the pH of minimum solubility of calcium phosphates (14, 32). Any change in the pH of soils, either by liming or the use of acid-forming materials will, therefore, affect the inorganic phase of the phosphorus cycle by tending to convert one form of phosphorus to another and thereby altering plant availability. But factors besides soil reaction may affect the availability of inorganic phosphates. What is the effect of magnesium, silica and other soil constitutents? Why, for example, is there so much difference in the availability of phosphorus in different types of calcareous soils? Before much further progress can be made on such problems, we will need more quantitative information on the specific compounds in different soils and a better understanding of their relation to the rest of the phosphorus cycle.

ORGANIC PHOSPHORUS CONTENT OF SOILS

It is the organic phosphorus of soils, plants, and microorganisms, that is of particular interest in the dynamic biological phases of the cycle. Compounds of organic phosphorus are more complex than the inorganic compounds, and they have received much less study. Some recent investigations, however, particularly those that have been carried on at MacDonald College, Quebec (12, 13, 36, 38, 39) and in

our laboratories at Ames (5, 6, 20, 21, 22, 26, 27, 28, 35) have given emphasis to this phase of the phosphorus cycle.

Data based on improved methods of extraction show that the organic phosphorus in the surface layers of many soils constitutes at least one-third, and in some cases, such as in Prairie soils, as much as two-thirds of the total phosphorus (20, 22). The amount decreases with depth in the profile as would be expected from the decrease in organic matter. A limited amount of data indicates that the N:P ratio of soil organic matter is about 10:1 in the surface layers of mineral soils, and usually somewhat higher in the lower horizons. These variations are undoubtedly of some significance, but present information is too limited to provide a satisfactory explanation. It is of interest to note that the N:P ratio in the organic matter is not very far different on the average from the N:P ratio in plants and microorganisms. This and other evidence referred to later indicate that the organic phosphorus of plant residues and soil organic matter may be as rapidly mineralized as is the organic nitrogen.

NATURE OF ORGANIC PHOSPHORUS COMPOUNDS IN SOILS, PLANTS, AND MICROORGANISMS

Until recently, our knowledge of the type of organic phosphorus compounds found in soils was based exclusively on two indirect lines of evidence, (a) the types of phosphorus compounds found in plants and microorganisms, and (b) the decomposition products isolated from soils—products which might be expected to be formed from the type of compounds returned to soils in plant residues.

It is established that three general types of compounds make up the bulk of the organic phosphorus in plants. These are phytin, phospholipids, and nucleic acids. Of these, the latter is found in largest quantities. Nucleic acid, combined with protein to form nucleoprotein, is also the dominant type of organic phosphorus compound in microorganisms. Phytin, the calcium-magnesium salt of inositol hexaphosphoric acid, is found principally in seeds where it makes up as much as 75 per cent of the phosphorus present. In other parts of the plant phytin apparently occurs only in small amounts, although the data reported are inadequate and conflicting. Phospholipids, such as lecithin, are essential constituents of cells, but in general make up only a small part of the total organic phosphorus content of plants, probably averaging less than five per cent. Soil studies indicate that phospholipid phosphorus is present in soils in trace amounts only (12).

Chemical studies have long ago established the fact that the organic decomposition products of nucleic acids—the nitrogen-bases and carbohydrates—do exist in soils, or at least can be obtained upon acid hydrolysis of soil extracts containing organic phosphorus (31). Moreover, inositol, the organic part of the phytin molecule, has also been isolated from soils upon acid hydrolysis of organic phosphorus preparations (40). Because of inadequate methods, however, no indication was thus obtained of the amounts of organic phosphorus compounds present. Thus, for many years the evidence for the existence of phytin and of nucleic acid types of compounds in soils was

entirely circumstantial, and no quantitative data were available. Recently, however, Bower (5) definitely established the presence of phytin and phytin derivatives in soils representative of the Prairie, Wiesenböden, and Gray-Brown Podzolic great soil groups. He showed that the inositol-phosphorus ratios of the compounds isolated corresponded nearly exactly to those in phytin and inositol triphosphate. Moreover, he developed a method for separating the phytin from the nucleic acid fraction of soil organic phosphorus and for determining the amounts present. In three soils studied, he found that 40 to 49% of the total organic phosphorus was present as phytin and phytin derivatives. The latter constituted about one-fourth of the phytin fraction. Further evidence as to the nature of the soil organic phosphorus fractions separated was provided by dephosphorylation tests with sodium hypobromite and various enzymes, which showed that the fractions behaved like phytin and nucleic acid, respectively (6).

THE AVAILABILITY OF ORGANIC PHOSPHATES TO PLANTS

The major question is, "Is this large reserve of phosphorus present as phytin and nucleic acid types of compounds involved actively in the phosphorus cycle? Is it much of a factor in determining the phosphorus requirement of soils? Or is it largely a "frozen asset", like the phosphorus in apatite, that is important only in the long-time consideration of soil fertility but is too slowly available to be an important factor in meeting the immediate or even year by year needs of the crop.

The fact of nitrogen mineralization and of correlated changes in total nitrogen, total carbon and total organic phosphorus in soils (22) furnishes strong circumstantial evidence as to the active part played by soil organic phosphorus in the phosphorus cycle. On the other hand, the fact that many soils high in organic phosphorus are deficient in available phosphorus has been responsible for the suggestions that organic phosphorus may not be important in plant nutrition. Experiments with pure organic phosphorus compounds in culture solutions have shown, however, that phytin and lecithin are directly absorbed by plants and that nucleic acid is so readily mineralized by enzymes on plant roots that it was not possible to determine whether the phosphorus was being absorbed in the organic or inorganic form (27). What then is the explanation for the fact that soils high in total organic phosphorus or in phytin and nucleic acid forms may be low in available phosphorus? The obvious assumption would be that the phytin and nucleic acid are made insoluble by reaction with other soil components; and that dephosphorylation, in the case of the nucleic acid fraction, does not take place as readily in soils as in pure solutions. Both of these assumptions have been shown to be true.

In the case of phytin the available evidence indicates that its reactions in soils are analogous to the reactions of inorganic phosphates. Just as phosphoric acid forms calcium or ferric salts, depending on the acidity of the solution and the presence of calcium and iron, so does phytic acid react in the formation of calcium and ferric phytates (1,

38). In acid soils, therefore, we can expect phytin to be present in relatively insoluble iron as well as aluminum phytates. And in fact phytin does become relatively insoluble and unavailable to plants when added to acid soils. Bower (6) found a very high correlation between the recovery of added phytin by oats and the percentage base saturation of the soils, the coefficient of correlation being + 0.95. In acid soils phosphorus recovery was very low whereas in an alkaline soil of pH 7.4 the recovery was substantial, amounting to about one-third as much as with monocalcium phosphate. Moreover, the amounts of phytin fixed by the soils, as measured by solubility in weak acid, showed an inverse relationship with the recovery of phosphorus by oats ($r = -0.92$). Monocalcium phosphate was fixed to a much less extent and was more available to plants. Thus, the accumulation of phytin in soils is not the result directly of a low rate of mineralization, but primarily because of its low solubility. Like inorganic phosphate its solubility is especially low in acid soils because of the formation of insoluble salts of iron and aluminum, these salts being even less soluble than the inorganic phosphates of iron and aluminum.

With respect to nucleic acid, the gaps in our knowledge are even greater. The accumulation of the nucleic acid type of compounds in soils is not readily reconciled with their rapid dephosphorylation by enzymes in culture solutions. Moreover, several investigators have found that free nucleic acids undergo rather rapid although not complete mineralization when added to soils. In some experiments the phosphorus added as nucleic acids is found to be nearly as readily available to plants as that added in the form of soluble inorganic phosphates (4, 19). It is evident, therefore, that most of the nucleic acids in soils do not exist in a simple form. Either they are physically inaccessible because of their being imbedded in slowly decomposable materials or they are there in compounds that are not readily attached by enzymes and mineralized. In either case it is apparent that they are split off in the process of extraction of soils with solutions of sodium or ammonium hydroxides for it has been shown that organic phosphorus in alkali extract of soils is easily dephosphorylated by nuclease enzymes (6, 26).

What then are the probable compounds or forms in which nucleic acid is combined in soils and stabilized against dephosphorylation? Recent data by Bower (6) provide at least a partial explanation. He studied not only the adsorption of three types of nucleic acid materials by clay minerals commonly found in soils but also the effect of such adsorption on the subsequent rate of dephosphorylation. Since several investigators had found that mineralization of nucleic acid was lower in strongly acid, than in less acid soils, he conducted his adsorption studies in the pH range of 2 to 7. In brief, he found that guanine nucleotide and nucleic acid were rapidly adsorbed by clays, especially by montmorillonite, and that this adsorption caused a marked reduction in the rate of mineralization or enzyme hydrolysis. The more acid the clay the greater was the adsorption and the lower the release of inorganic phosphate. During a four-day period of reaction montmorillonite caused a reduction in the amount of nucleic

acid mineralized from 91 to 16 per cent. Of even greater significance was the fact that nucleo protein was completely adsorbed by the montmorillonite clay at all pH values studied and that its dephosphorylation by bran enzymes in a four day period was reduced to only three per cent.

Since nucleic acids are largely present in plant and animal cells combined with proteins as nucleo-proteins it is evident that their absorption by clays—as plant and microbial residues are returned to soils—may in part explain the accumulation of nucleic acid types of phosphorus compound in soils. It must also be kept in mind that relatively small additions of nucleoproteins are returned to soils at any one time under natural conditions and that this would make possible more complete adsorption by clays and even greater stabilization than was found in these laboratory experiments. Reactions between nucleic acids and other soil constituents may also be responsible for the accumulation of the nucleic acid type of phosphorus compounds in soils.

The fact then that phytin and nucleic acid phosphorus accumulate in soils during processes of soil formation and are continually being returned to soils in dead microbial cells and plant and animal residues, and stabilized against rapid mineralization does not mean, however, that these organic phosphates are relatively unimportant in plant nutrition. In fact, there is increasing evidence that the place of soil organic phosphates in the phosphorus cycle has not been fully appreciated. Variations in the rate of mineralization of the organic phosphorus of soils are undoubtedly an important factor in explaining the differential response of crops to phosphorus fertilization and the discrepancies often encountered in relating the results of soil tests to such responses. Most chemical tests for estimating the readily available phosphorus in soils measure only soluble inorganic phosphorus. This may explain why soils high in organic matter often give very low tests for "readily available" phosphorus and yet show little response to phosphate fertilization.

MINERALIZATION OF ORGANIC PHOSPHORUS

The fact that the organic phosphorus of soils decreases upon cropping was shown by Schollenberger (30) over 25 years ago. Cultivated soils were found to have lost about the same amounts of organic as of inorganic phosphorus since they had been brought under cultivation. More recently, Pearson found in a study of eight cropped and comparable virgin soils in Iowa (6), that cropping had on the average reduced the inorganic phosphorus content of soils by 55 ppm, but the organic phosphorus by 83 ppm. In view, especially, of the continual additions of organic phosphorus in crop, animal and microbial residues these data are quite significant in showing that organic phosphates are not "frozen assets".

Short-time studies of the transformations in soils are of even greater value, however, in determining the role of organic phosphorus in the phosphorus cycle and in plant nutrition. Using the same eight pairs of virgin and cropped Iowa soils used by Pearson and referred to above,

Bower (6) found that during a month's incubation at 35°C the virgin soils released an average of 39 ppm of phosphorus from the organic form while under the same conditions the cropped soils released from 1 to 18 or an average of 11 ppm. Similar results have been obtained by Thompson (35). Since crops usually require less than 20 pounds of phosphorus per acre, it is evident that the organic phosphorus compounds of many soils may make a significant contribution to the phosphorus absorbed by crops, especially from Prairie soils that contain at least a third of their total phosphorus in organic forms.

From the standpoint of soil management practices it would, of course, be of considerable practical importance to know from what type of compounds the organic phosphorus is being released over short periods of time. Does it come from a large supply of relatively resistant materials or end products that are only slowly being decomposed by the action of soil microorganisms, or does it come from a much more limited supply consisting of compounds from more recent plant and microbial residues? Our present knowledge of this point hardly justifies a conjecture. Of interest in this connection, however, are some recent studies by Thompson (35) in which he obtained a close relationship between the amounts of nitrogen and of phosphorus mineralized in soils during one month's incubation at 35°C, the correlation coefficient found being 0.91. This may indicate that the nucleic acid type of compounds present in dead microbial cells and plant residues of recent origin are of primary importance.

The information available regarding the changes in the phosphorus compounds of crop residues as the residues decompose in soils is also very limited. Studies of decomposing plant materials outside of soils show, however, that during the early stages of decomposition the amount of organic phosphorus may actually increase at the expense of the inorganic fraction. Then as the energy supply and the number of microorganisms in the decomposing residue decreases, the inorganic phosphorus is gradually released (8).

THE ROLE OF SOIL MICROORGANISMS

These considerations bring us to the role of microorganisms in the phosphorus cycle. Much of the interest and work in this field has been concerned with the effect of microorganisms in the liberation of phosphorus from insoluble mineral phosphates. It is recognized that the large amount of carbon dioxide liberated by soil microorganisms may have a marked effect in increasing the availability of basic calcium phosphates, especially in neutral or alkaline soils, (18). Under certain conditions the solubility of mineral phosphates may also be slightly increased in the nitrification and sulfofication processes. In general, however, it would seem that the two most important specific roles of microorganisms in the phosphorus cycle are (a) the production of enzymes, such as nucleases, which are necessary for the mineralization or dephosphorylation of organic phosphorus and (b) the immobilization of available inorganic and organic phosphorus compounds present in soils. In general, investigators have been much more concerned with the first of these effects, the liberation of phosphorus,

than with the opposite, the immobilization or biological fixation of phosphorus by the soil microorganisms.

Little information is available as to how soils may differ in their content of dephosphorylating enzymes, but recent studies by Rogers (26) on sterilized soils indicate that nuclease enzymes are probably generally present in soils.

The amount of phosphorus immobilized in the bodies of soil microorganisms at any one time may be considerable, especially when large supplies of available energy materials in the form of manures and plant residues are added to soils (33). Just as materials of wide C/N ratio will result in competition between the microorganisms and the higher plants for the available nitrogen present, so also may there be a competition for the available phosphorus when plant or animal residues low in phosphorus and high in energy materials and nitrogen are added to soils. The addition of dried blood to a soil low in available phosphorus, for example, was found by Chouchak (10) to cause such an intensive development of soil microorganisms and such a marked immobilization of the phosphorus that yields of millet were materially decreased except where phosphate fertilizers were also added. Where chloroform had been added to inhibit microbial development the inorganic phosphorus was actually increased. This investigator also obtained very striking results with a soil that had been sterilized and reinoculated (9). The large release of nitrogen and energy material resulting from sterilization caused such a large immobilization of available phosphorus by the intensive development of microorganisms that the yield of millet where no phosphorus had been added was reduced from 27 to 1 gram per pot, whereas with phosphorus added the yield on the sterilized soil was about three times as much as on the unsterilized soil.

How important this biological immobilization of phosphorus may be under various soil conditions is a problem that needs careful investigation. It would seem, however, that in soils low in available phosphorus, the addition of plant materials low in phosphorus but high in nitrogen and energy material may easily lead to phosphorus starvation of growing plants. On soils high in available phosphorus, on the other hand, the temporary immobilization may be beneficial for it may decrease inorganic fixation of phosphorus and still allow sufficient amounts of phsophorus to become available to plants gradually during their growth.

The type of microorganisms involved may also play an important role not only in the amounts of phosphorus immobilized but also in the kind of compounds formed and in the rate at which inorganic phosphorus is subsequently released. What may be the difference, for example, between fungal and bacterial populations?

The role of microorganisms in the P cycle is, therefore, a very dynamic one. Changes in microbial population from day to day, in response to various environment factors may quickly alter the amounts of available phosphorus in soils. There is every reason to believe that the significance of such everyday occurrences as waterlogging, drying, heating, and freezing of soils is not fully recognized nor evaluated. By increasing or decreasing the microbial population and by changing

its character these soil conditions may either result in the liberation of P for immediate use, or in the immobilization and conservation for future use.

SOIL MANAGEMENT PRACTICES AS MODIFIERS OF THE PHOSPHORUS CYCLE

From what has already been said, it is evident that soil management practices may greatly modify the amounts of available phosphorus found in soils. They do so in three ways, *viz.*, (a) by changing the type of compounds present, (b) by affecting the solubility of these compounds, and (c) by altering the microbiological status of the soil. Nearly every one of our common soil management practices such as liming, fertilization, drainage, tillage, and the additions of manures and crop residues may be expected to affect phosphorus availability in at least two of these ways. Liming, as previously mentioned, affects not only the kind of inorganic phosphate compounds and their solubility but also the kind and solubility of phytin compounds. Moreover, liming may favor the mineralization of the nucleic acid type of phosphorus compounds by reducing their absorption by clays, as well as by increasing the activity of nuclease enzymes (28). To the extent, however, that liming may cause rapid increases in microbial numbers, and to the extent that liming in excess may result in the formation of basic calcium phosphates and possibly basic calcium phytates, the availability of phosphorus may at times be actually reduced (25).

Phosphate fertilization is, of course, the most common means of increasing the easily soluble or available phosphate compounds of soil. Unfortunately, the added phosphates usually revert rather rapidly in the soil to less available forms (24). This has been the subject of many excellent investigations and although a number of management practices have been developed to minimize fixation, too large a proportion of the million and a half tons of phosphoric acid added in fertilizers annually reverts to the "frozen assets" class. As we learn more about the phosphorus compounds of soils and the phosphorus cycle this large loss should be reduced.

As to the effects of drainage and tillage practices on the phosphorus cycle, little information is available at present. It is probable, however, that through their effects on the oxidation and reduction conditions in soils and also on the microbial population they may have significant effects on phosphate availability.

Of all the important soil management practices, manuring is probably the least understood from the standpoint of its effect on the phosphorus status of soils. The so-called reinforcement of manure with phosphate fertilizer has been generally recognized as advantageous. Manure is relatively low in total phosphorus but this is perhaps not the most important reason for the beneficial effects of phosphate supplements. Little information is available on the forms in which phosphorus occurs in manure. It is probable that the compounds present vary considerably. Manure from animals fed a ration high in cereal grains may be high in phytin, for phytin is evidently not as

readily dephosphorylated in the digestive tract as other organic phosphorus compounds. On the other hand, manure from cattle fed roughages, which are normally quite low in phytin, may contain most of the organic phosphorus as nucleo proteins in the form of resynthesized material present in microbial tissue. There is also a wide range in the nitrogen and energy materials in manure which will greatly affect the biological fixation or immobilization of phosphorus during its decomposition. It is possible, therefore, that under some conditions, at least, manuring may actually accentuate the deficiency of phosphorus in soils and necessitate larger applications of phosphate fertilizers. The same may also be true in the case of certain green manuring practices.

THE LARGER CYCLE

Reference has already been made to the use of phosphate fertilizers, the most important external method by which the soil phosphorus cycle can be "recharged". In a sense this is a phase of a world phosphorus cycle—a cycle in which the phosphorus accumulation in our large phosphate deposits and the return of this phosphorus to soils in the form of fertilizers are counterparts. A consideration of the relation between phosphate fertilizer needs and use is beyond the scope of this discussion. It may be pointed out, however, that on the basis of recent estimates, phosphate fertilizer consumption in this country is still only about half of that required for efficient crop production (15). On the world basis, the discrepancy between need and use is probably even greater.

The replenishment of phosphorus in surface soils from deeper horizons through the action of deep rooted crops is, as previously mentioned, the other important method by which phosphorus is brought into the biological phase of the phosphorus cycle. It is well established that many of our most fertile soils contain large reserves of subsoil phosphorus (23) and there is growing evidence that certain crops, such as the deep-rooted legumes, may make considerable use of this phosphorus. Here again we need quantitative data if we are to establish soil and crop management practices that make the fullest and most efficient use of our phosphorus resources.

Soil and crop management practices also have important over-all effects on losses of phosphorus from the revolving fund. Excessive erosion as a result of poor soil management practices may be expected to decrease the available phosphorus supplies in most soils. In prairie soils the horizon below the plow layer is usually much lower in total and dilute acid soluble phosphorus than the surface soil; and crop response data show that eroded areas of Prairie soils are much more deficient in available phosphorus than are uneroded areas. Moreover, it has been found that the losses of residual fertilizer phosphate by erosion may be quite large under certain conditions (29).

CONCLUSION

In concluding this discussion, I would like to emphasize again that there are many gaps in our knowledge of the phosphorus cycle. And

it is obvious that these gaps need to be filled if we are to maintain soils at a high level of fertility and use phosphate fertilizers efficiently. Many aspects of our knowledge are still in the descriptive stage. We need better quantitative information on the amount, and availability of the various phosphate compounds present in soils, both organic and inorganic. Such information is essential to the improvement of present methods of estimating the phosphorus need of soils, particularly of soils high in organic matter and those neutral and alkaline in reaction. It is also essential to the establishment of improved soil and crop management practices.

Increasing attention should be given, in particular, to the organic phosphorus compounds, their composition and their transformations in relation to plant availability. We need to know more about the dynamic, short-time changes in the cycle resulting from the activities of soil microorganisms, and the effect of various soil conditions on such transformations. Present indications are that the answers to some of these problems are not far off. Much progress has been made in recent years, and the outlines of the picture are much clearer. Moreover, radio-active phosphorus offers particular promise in establishing the nature and extent of the transformations in the phosphorus cycle, as well as in determining the role of various soil phosphorus compounds in plant nutrition. Isotopic forms of nitrogen and carbon have already been used successfully in giving us the beginnings of a new concept regarding the nitrogen and carbon transformations in soils (4). Together with the use of radio-active phosphorus they should make possible a much better understanding of the relation between the nitrogen, carbon and phosphorus cycles in soils and of soil organic matter chemistry generally.

And finally, I would emphasize that the important advances made recently have come from pooling skills of various specialists. These results make it clear that future progress lies along that line.

LITERATURE CITED

1. Anderson, R. J. Phytin and pyrophosphoric acid esters of inosite, II. New York State Agr. Exp. Sta. Tech. Bul. 21. 1912.
2. Barbier, G., Chabannes, J. and Miallet, P. Absorption des ions phosphoriques a la surface des colloides argileux par l'intermédiare des alcalino-terreux. Ann. Agron. (N. S.), 16:7–33. 1946.
3. Bertramson, B. R., and Stephenson, R. E. Comparative efficiency of organic phosphorus and of superphosphate in the nutrition of plants. Soil Sci., 53:215–226. 1942.
4. Broadbent, F. E., and Norman, A. G. Some factors affecting the availability of the organic nitrogen in soil—a preliminary report. Soil Sci. Soc. Amer. Proc., 11:264–267. 1947.
5. Bower, C. A. Separation and indentification of phytin and its derivatives from soils. Soil Sci., 59:277–285. 1945.
6. ————. Studies on the forms and availability of soil organic phosphorus. Iowa Agr. Exp. Sta. Res. Bul. —, —.
7. Bray, R. H., and Dickman, S. R. Adsorbed phosphates in soils and their relation to crop responses. Soil Sci. Soc. Amer. Proc., 6:312–320. 1942.
8. Chang, Sing Chen. The transformation of phosphorus during the decomposition of plant materials. Soil Sci., 48:85–99. 1939.
9. Chouchak, D. Sur l'antagonisme entre les plantes cultivées et les bactéries du sol dans leur nutrition minérale. Compt. Rend. Acad. Sci., 185:82–85. 1927.

hybrid-combining abilities of lines may be determined in the early generations of inbreeding. In the selfing-top-crossing system each generation of selfing is alternated with a yield test of the top-crossed seed of selected plants. The theoretical advantages of this procedure are its provision for selection both on the basis of yielding ability and visual characteristics, and also for the elimination of low-yielding strains early in the inbreeding program. Thus, in each generation of inbreeding after the first, further selection and testing is confined to the known high-yielding portion of the population rather than to a random sample, as is the case with the usual inbreeding methods. Although the method has been practiced by us since 1934, successive droughts have prevented an adequate test of its usefulness. Its theoretical advantages justify an extensive study of its practical possibilities.

After the first or second generation of selfing, the ears of selected plants are too small to furnish adequate quantities of both selfed and top-crossed seed. Under these circumstances it is necessary to produce top-crossed seed by using an open-pollinated variety, or some suitable hybrid tester, as the female parent. When this procedure is followed the number of plants required adequately to sample the seed parent is important. The present report is concerned with an investigation to determine the variance among the top crosses on the ears of individual plants of a variety as a basis for computing the number of plants required in samples to reduce effectively the variance among sample means to a point where it becomes negligible when compared with the variance ascribable to random error.

MATERIAL AND METHODS

The experimental material consisted of top-crossed ears of two varieties. The first lot (experiment A) included 40 ears of Reid Yellow Dent subdivided into two 20-ear samples. A plant of open-pollinated Reid was used as the male parent to make one set of 20 top-crossed ears and a plant of a long-time inbred line served as the male for the other set.

The second lot (experiment B) consisted of six samples of 20 top-crossed ears made within the variety Krug.[5] Each 20-ear sample had as its male parent a plant from a progeny grown from a first generation self. Thus, six different plants were used as males to pollinate the 120 ears. The two lots of seed, Reid and Krug, represent unselected samples except for the one limitation that only ears having 300 or more kernels were used. Since the seed was produced by hand pollination, there is no necessary relation between the number of kernels produced and the potential size of the ear.

The top crosses on plants of the two varieties (40 plants of Reid and 120 plants of Krug) were compared for yield in separate experiments. Fifteen replications of five hills each were planted from each top-crossed ear. Planting was in randomised blocks. Four kernels were planted per hill and later thinned to three plants where possible.

RESULTS

The analyses of variance for the plat yields of the two experiments ear presented in Table 1. In experiment A the variance among the

[5]The writer is indebted to Dr. Merle T. Jenkins for this seed.

top-crossed progenies is highly significant. The variance due to progenies is further separated into two components, one degree of freedom being associated with the difference in male parentage and the other 38 degrees of freedom with the differences among the female-parent plants of the Reid variety. The variance among progenies after removing the effect of the male parents is highly significant, indicating a real difference in yielding ability.

TABLE 1.—*Analyses of variance of the plat yields for the top-crossed progenies of 40 and 120 plants of Reid Yellow Dent and Krug, respectively.*

Source of variation	Experiment A (Reid)			Experiment B (Krug)		
	Degrees of freedom	Sum of squares	Mean square	Degrees of freedom	Sum of squares	Mean square
Replications	14	135.34	9.67	14	485.97	34.71
Progenies	39	386.18	9.90*	119	537.91	4.52*
Male parentage	1	6.61	6.61	5	119.81	23.96*
Female parentage	38	379.57	9.99*	114	318.10	2.79*
Error (male parent × replications)	14	42.41	3.03	70	203.99	2.91
Error (female parent × replications)	532	1,115.65	2.10	1,596	2,527.32	1.58
Total	599	1,679.58	—	1,799	3,755.19	—

*Highly significant; exceeds the 1% point.

The two male parents in this group were chosen to represent extreme differences in heterozygosity. It was thought that this difference in heterozygosity might indicate a difference in the number of plants required for adequate representation. However, the difference between the two male parents associated with only a single degree of freedom is not significant, falling short of the 5% point. When the progenies were tested for heterogeneity of variance by a method suggested by Brandt,[6] the value for X^2 (Chi^2) was found not to be significant.

In experiment B the variance due to progenies is highly significant. When this variance is subdivided into the portions due to male and female parentage, each portion likewise is highly significant. It is evident that both the male parents and the female parents differed significantly in their transmission of yielding ability. In an analysis of variance of stand, only the variance due to differences in male parentage was significant. This and an analysis of the covariance between yield and stand indicates that part of the differences in the

[6]The writer is indebted to Dr. A. E. Brandt for a description of this method prior to its publication. The method is based on the fact that $X^2 = \frac{(n-1)v}{u}$, where v represents any observed variance among n variances and u is their theoretical variance. In the present case a significant X^2 value indicates that the yield variances of the several top-crossed plants differ more than would be expected by random sampling from a uniform population of variances. A short description of the method is presented in Snedecor's *Statistical Methods*, pages 196, 197.

yields of progenies of the six males was due to their differential transmission of germinative ability. Use of the covariance between stand and yield permits a reduction in the error variance in this experiment from 1.58 to 0.98.

The observed variations in yield among the individual ears in these experiments are of interest in connection with the system of breeding outlined in the first part of this paper. In experiment A the mean yield was 55.5 bushels per acre, with extremes ranging from 40.1 to 71.2 bushels. In experiment B the mean yield was 45.4 bushels, with extreme yields of individual ears ranging from 26.9 to 62.8 bushels per acre. The highest yielding entry represents an increase in yield of 28.3 and 38.3% above their respective mean yields.

The wide spread in yielding ability among individual ears in each of these varieties suggests that a system of breeding which will permit of the concentration of efforts on the highest yielding plants and their progenies should result in a considerable increase in efficiency. The efficiency will be greatest in the first generation of selection and will decrease with each generation of inbreeding.

An estimate of the number of plants of the open-pollinated varieties required for adequate representation was obtained in the following manner. In experiment A the variance due to experimental error is 2.10. The variance among progenies of the Reid plants is 9.99, leaving 7.89 as the additional variance among progenies. For a 10-plant sample, the expected variance then would be $7.89/10+2.10$ or 2.89. The data presented in Table 2 were calculated in this way. Estimates of the number of plants required for adequate representation have been computed before and after adjusting yield on the basis of its regression on stand.

TABLE 2.—*Calculated variances between female progenies for samples of various numbers of progenies on the basis of observed variances among the top-crossed progenies of individual plants.*

Plants per sample	Calculated variance			
	Experiment A		Experiment B	
	No stand correction	Corrected for stand	No stand correction	Corrected for stand
1	9.99	10.14	4.52	2.25
5	3.68	3.62	2.17	1.23
10	2.89	2.81	1.87	1.11
15	2.63	2.53	1.78	1.06
20	2.49	2.40	1.83	1.04
25	2.42	2.32	1.70	1.03
30	2.36	2.26	1.68	1.02
50	2.26	2.15	1.64	1.01
100	2.18	2.07	1.61	0.99

The results from the two experiments are in general agreement. In experiment B it appears that 10 plants would probably form an adequate sample. Increases in sample size above 20 plants result in

very slight reductions in the calculated variance. The variance associated with error and with progenies is considerably higher in experiment A than in experiment B. However, in this case also 10 to 20 plants would provide a fair sample. Increases in sample size above 20 plants do not result in important reductions in the calculated variance. For the majority of experiments, it appears that a 10-plant sample would be entirely adequate.

In the calculations presented in Table 2 it has been assumed that the use of means would give essentially the same result as the use of a bulked sample. The error variance should be essentially the same in both cases, providing the size of plats and number of replications remains unchanged. One might expect that the variance associated with female parentage would be materially reduced by the use of a bulked sample since plat variability would also be reduced. The design of this experiment would doubtlessly have been improved by the inclusion of a series of bulked samples made up from various combinations of individual ears. It was not possible to do this because of the limitation imposed by the number of seeds per ear.

These calculations of the theoretical variances of samples of various sizes assume that each plant is equally represented. Since the usual practice is to bulk the seed from the top-crossed ears and to prepare planting samples from these bulked lots, it was first thought that this might introduce a serious error since it superimposes a second sampling problem.

The importance of this source of error has been examined. The following assumptions form the basis for these calculations: A 20-ear sample, each ear having 200 kernels, is bulked to give a total of 4,000 kernels. The size of the theoretical sample to be drawn was set at 20 kernels, because of the labor involved in expanding the binomial ($.05 \times .95$), though the usual sample size for a single replication would be 60 to 100 kernels. With these limitations, the mean value to be expected is that in each 20-kernel sample a particular ear will be represented by one kernel. This is a Poisson distribution; consequently, the variance is equal to the mean, being 1. This indicates that, as a rough approximation, considering the 5% level of significance, one might expect the means of actual samples to fall within the range of $1 \pm .439$. Since this distribution is so highly skewed, it may be preferable to calculate the probability from $.95^{20}$ or .36. This value (.36) indicates a much higher probability, one chance in three, that any particular ear may be excluded from the 20-kernel sample. It is apparent, on the basis of either estimate, that no serious error will be introduced by sampling from bulked lots of seed.

In actual practice, the individual ears will not have equal numbers of seeds and will contribute in differing amounts to the bulked sample. In the absence of some serious bias, each ear will tend to be drawn in the same proportion that it contributes to the total sample. This would not be a serious source of error if more than 10 ears were used, unless several of the ears are represented by relatively small quantities of seed.

CONCLUSIONS

A study of the variance among the top crosses on individual plants of two open-pollinated varieties in relation to the variance associated with random error indicates that the variance of the means of samples of 10 to 20 plants will be unimportant, as compared with the variance ascribed to random error.

The preparation of seed for planting from bulked seed from this many plants would not introduce serious errors unless the size of the samples drawn from the bulked lot is small or the individual plants contribute widely different numbers of seeds to the total population.

THE EMERGENCE OF GRASS AND LEGUME SEEDLINGS PLANTED AT DIFFERENT DEPTHS IN FIVE SOIL TYPES[1]

R. P. MURPHY AND A. C. ARNY[2]

DURING the last few years many farmers and experiment station workers have realized that the amount of seed planted of many of the grasses and small-seeded legumes was far in excess of the number of seedlings obtained in the initial stand. Such experiences have probably been due to the effect of environmental influences, species of plant, depth of planting, soil type, and other less important factors upon the total emergence. Although these factors, with the exception of the environmental effects, may be controlled in part, the influences of any one of these factors or of the interactions among these factors have not been studied extensively by experimental methods.

Farmers have been sowing too deeply in some cases and some of the recommendations for depth of planting grasses and legumes found in the literature involve depths which were probably too deep for maximum seedling emergence. Since a good initial stand is necessary in the establishment of meadows and pastures, it was believed desirable to determine as definitely as possible the effect of the above variables upon the primary emergence.

REVIEW OF LITERATURE

Love and Hanson (2)[3] were among the first to study the effect on stand of different depths of planting. Their investigations were conducted in the greenhouse with crested wheat grass. Two hundred seeds were planted at several depths in clay soil of good tilth.

They observed that seed of crested wheat grass germinated well upon the surface of the soil when there was sufficient moisture. However, in the field, if the surface was dry, the best depth at which to plant was usually between one-fourth and one-half inch depending upon the dryness of the surface soil.

Love and Hanson (2) reported a similar experiment with brome grass. They concluded that the maximum depth at which emergence occurred was 3 inches. Five per cent of the seedlings emerged at this depth. About 65% of the seedlings emerged from ⅛ to 1 inch plantings.

Kirk, Stevenson, and Clarke (1) report depth of seeding studies with crested wheat grass which were carried out in the greenhouse. A similar field test showed clearly that in both spring and fall seedings the best stands were obtained from the ½-inch depth of planting. They state that planting too deeply has been responsible for many failures with this crop in Saskatchewan.

McMichael (3), in a study to determine the most satisfactory depth at which to plant a number of species of grasses, found that brome grass gave good stands

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[1]Part of a thesis submitted by the senior author at the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science. Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1646 of the Journal Series, Minnesota Agricultural Experiment Station.

[2]Instructor and Associate Professor, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 28.

down to and including the 2-inch depth. The emergence was good for the fairway and forage strains of crested wheat grass at ½ inch or shallower depths with only 50% emergence at the ⅛ inch depth of planting. Kentucky bluegrass produced the best stand from the surface planting while the ½ inch planting gave a very poor emergence.

The rate of emergence was also determined for these grasses by McMichael. Nearly all the plants of brome grass and crested wheat grass emerged between 5 and 15 days after planting, but the majority of the Kentucky bluegrass seedlings required from 10 to 20 days to emerge.

Stevenson (4) recently reported that in Saskatchewan deep seeding has been responsible for many failures with sweet clover. He found that 1 inch was the maximum planting depth even on the lighter soil types.

MATERIALS AND METHODS

Five important soil types which occur commonly in Minnesota and which vary widely in texture were obtained for these studies. The types selected included Carrington heavy silt loam and Clinton silt loam from Fillmore County, Clarion silt loam from Redwood County, Fargo silty clay loam from Wilkin County, and Merrimac loamy fine sand from Ramsey County. These soils taken from the surface 6 inches were brought to University Farm in the summer of 1936.

The moisture equivalents and pH values of these soil types are given in Table 1.

TABLE 1.—*The pH values and moisture equivalents of the soil types used in this study.*

Soil type	pH	Moisture equivalent %
Merrimac loamy fine sand	6.7	6.89
Clinton silt loam	6.2	20.35
Carrington heavy silt loam	5.6	24.18
Clarion silt loam	6.0	26.24
Fargo silty clay loam	6.7	34.16

The Merrimac loamy fine sand dried rather quickly following watering because of the low water-holding capacity. However, the surface of this soil did not crack since it was very low in colloidal material. The surfaces of the Carrington heavy silt loam and especially of the Clinton silt loam remained damp for some time after watering. This may be explained by the rather high moisture equivalent combined with a rapid rise in capillary water due to the high content of silt. The surface did not crack badly as the soils were not high in colloidal matter. The Clarion silt loam reacted much the same way but dried out faster on the surface. The Fargo silty clay loam, however, was very different. The surface dried rapidly, often in one day, after rains or watering, but the deeper layers remained very wet. The high moisture equivalent permitted the soil to hold a high percentage of water, but the slow capillary movement due to a high content of clay, did not maintain a moist surface. In addition, the surface cracked severely because of the high content of colloidal matter. During the course of these experiments none of these soils developed a heavy crust which the seedlings were unable to penetrate.

The crop seeds used in the studies in both the greenhouse and field included, Grimm alfalfa, biennial white sweet clover, red clover, alsike clover, white clover,

timothy, brome grass, forage crested wheat grass, reed canary grass, and Kentucky bluegrass. Crop seeds used in the greenhouse studies only included sudan grass, Red Turghai millet, German millet, slender wheat grass, perennial rye grass, meadow fescue, orchard grass, and red top.

The percentage of germination was determined so that the same number of viable seeds could be planted for each crop at each depth. The studies were made in the greenhouse and in the field. The greenhouse experiments were made to obtain results for optimum conditions for emergence. The field studies were made to obtain results on emergence similar to what might be expected under actual field conditions.

Flats 16 inches square and 6 inches deep were used in both the greenhouse and the field studies. In the field, the surface soil was removed to a depth of 6 inches and flats without bottoms were fitted into place. These were then filled with the different soils and allowed to remain over winter before any plantings were made.

The depths of planting used in these studies were as follows: Surface, ½ inch, 1 inch, 2 inches, and 3 inches. These were determined accurately by removing the soil to the desired depth, followed by planting and replacement of the soil. The soil was packed slightly in an effort to approximate normal planting conditions. The surface planting was sprinkled lightly with soil to hold the seeds in place during rains or watering.

Notes on the emergence were taken each day after planting until no further seedlings appeared; consequently, the data collected include the rate of emergence for the variables as well as the total emergence.

Although the results for the emergence under field conditions are for only one season, the data are an average of two dates of planting with somewhat different environmental conditions prevailing during the times of emergence. The first planting, made May 4, developed under cool temperatures and a total precipitation of 4.23 inches which fell on seven different days. The surfaces of the soils were somewhat moist at all times. The second planting, made June 7, developed under variable environmental conditions. The soils were moist and in excellent tilth at planting time, but during the time of emergence the temperature was quite variable with five days over 80°F. During the time of emergence, only two rains fell, 1.38 inches on June 13 and 1.29 inches on June 17. However, as the results for the total emergence were very similar for the two dates of plantings, the field tests were summarized together.

At the conclusion of the greenhouse studies, the seed weights were correlated with total emergence from the five depths of planting. The weight of seeds was determined by an average of three separate lots of 1,000 seeds.

RESULTS

In these studies some of the differences in emergence among the legumes may be explained by the attacks of some of the "damping-off" fungi at the time of emergence or pre-emergence. This effect was more noticeable in the greenhouse than in the field. Sweet clover was the most severely affected, while red clover showed the least injury.

In Table 2 are given the results of emergence of seedlings for each crop from each depth of planting for the tests made on Carrington heavy silt loam.

TABLE 2.—*Percentage of total emergence from Carrington heavy silt loam.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	80	69	46	4	0	81	73	48	19	0
Sweet clover	68	54	30	0	0	65	51	43	12	0
Red clover	86	85	77	2	0	87	86	70	12	0
Alsike clover	80	75	29	0	0	74	64	51	0	0
White clover	87	67	40	0	0	88	76	54	0	0
Timothy	86	81	56	0	0	84	85	68	3	0
Brome	98	100	94	46	3	100	100	100	80	20
Crested wheat	82	82	58	4	0	82	84	73	21	0
Reed canary	82	87	70	37	1	93	84	76	54	17
Kentucky blue	56	46	9	0	0	83	62	24	0	0

As the surface of this soil type remained moist for some time in the field, the maximum seedling emergence for most of the crops came from the surface plantings and was very similar to the results in the greenhouse where conditions were most favorable. Kentucky bluegrass was the only notable exception to this as the emergence from all depths was much lower in the field than in the greenhouse, indicating that this crop was influenced more by changes in environmental conditions than were the other crops. Emergence from the ½ inch depth of planting was similar to that from the surface planting. Sweet clover, alsike clover, white clover, and Kentucky bluegrass seedlings did not emerge satisfactorily from the 1-inch planting in the field. From the 2-inch depth in the field the seedling emergence for brome grass was 46% and for reed canary grass 37%. The results from this depth were much higher for these crops in the greenhouse. The 2-inch plantings of brome grass in the field were fairly satisfactory.

The results from all tests from Clinton silt loam are given in Table 3.

TABLE 3.—*Percentage of total emergence from Clinton silt loam.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	77	70	34	4	0	66	52	31	0	0
Sweet clover	66	65	26	0	0	53	35	21	0	0
Red clover	86	78	48	3	0	72	65	45	0	0
Alsike clover	76	59	18	0	0	65	22	7	0	0
White clover	84	72	22	0	0	78	50	25	0	0
Timothy	92	68	32	0	0	88	60	49	0	0
Brome	100	95	81	32	1	100	100	98	36	3
Crested wheat	84	70	32	0	0	79	61	50	2	0
Reed canary	86	77	58	20	6	86	80	71	36	4
Kentucky blue	66	53	0	0	0	81	49	16	0	0

The best results on this soil type were also obtained from the surface planting since the soil remained moist long after rains or watering. The continually moist surface did not permit the soil to crack or crumble with the result that the seedbed became rather firm. Consequently, the total emergence from the deeper depths was low. Only brome grass, reed canary grass, and red clover gave an appreciable emergence from the 1-inch plantings in the field. Satisfactory emergence was not obtained from the 2-inch plantings in any of the tests with this soil type.

In Table 4 are found the average results from emergence from Clarion silt loam.

TABLE 4.—*Percentage of total emergence from Clarion silt loam.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	84	74	14	4	0	72	50	35	14	0
Sweet clover	70	64	15	4	0	58	44	35	11	0
Red clover	82	86	48	12	0	86	80	71	16	0
Alsike clover	69	72	18	0	0	67	58	46	0	0
White clover	82	80	24	0	0	88	76	65	1	0
Timothy	82	75	38	0	0	87	83	74	10	0
Brome	90	100	86	55	21	100	100	100	91	39
Crested wheat	70	73	54	8	0	88	79	71	16	1
Reed canary	63	80	68	29	3	97	88	81	66	24
Kentucky blue	39	38	6	0	0	89	70	33	0	0

Since the surface of this soil becomes more open and friable soon after rains or after watering, the results were somewhat different from those on the Carrington and Clinton soil types. In general, the ½-inch planting in the field produced an emergence as high or higher than that from the surface planting. Reed canary grass in the field tests gave a much higher percentage of emergence from the ½-inch plantings than from the other depths. Red clover produced a 48% emergence and brome grass, crested wheat grass, and reed canary grass produced an even higher percentage of emergence from 1-inch plantings in the field. A 55% emergence of brome grass was obtained from the 2-inch depth in the field. In the greenhouse, the emergence from the deeper depths was much higher than in the field. From this soil, 21% of the brome grass seedlings emerged from the 3-inch depth in the field which was much greater than the emergence on the Carrington or Clinton soil types from this depth.

The results from Fargo silty clay loam are given in Table 5 for all tests.

As the surface of this soil type dries very rapidly, the emergence from the surface plantings in the field was low for all crops. However, 75% of the brome grass, 72% of the crested wheat grass, and 70% of the alfalfa emerged under these conditions. In contrast to this, 26% of the reed canary grass and only 12% of the Kentucky bluegrass emerged

TABLE 5.—*Percentage of total emergence from Fargo silty clay loam.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	70	82	61	22	2	80	66	66	45	0
Sweet clover	54	63	51	16	3	66	52	39	19	0
Red clover	59	82	78	23	1	88	80	76	14	0
Alsike clover	43	73	47	0	0	84	56	46	0	0
White clover	46	85	58	0	0	89	76	72	0	0
Timothy	58	68	36	0	0	86	79	66	2	0
Brome	75	98	97	83	42	100	100	100	90	51
Crested wheat	72	74	55	9	4	92	73	69	24	2
Reed canary	26	78	80	28	7	96	92	86	54	26
Kentucky blue	12	37	3	0	0	80	62	24	0	0

from the surface plantings in the field. Thus, the data in these studies indicate that brome grass, crested wheat grass, and alfalfa seeds germinated and emerged better under drier soil conditions than were favorable for the other seeds. The emergence was highest for all crops planted ½-inch deep except reed canary grass which produced a slightly higher emergence from the 1-inch planting. Fair to good emergence from the 1-inch depth was noted for all crops except timothy and Kentucky bluegrass. In the field, brome grass gave 83% emergence from the 2-inch depth and 42% from the 3-inch depth of planting. Twenty-two per cent emergence occurred for alfalfa, 23% for red clover, and 28% for reed canary grass from the 2-inch planting in the field on this soil type. On the basis of these results somewhat deeper plantings appear to be advisable on this soil type than on the others tested in these experiments.

Emergence in the greenhouse was high from all depths and for all crops on this soil type. However, as shown by the field results, environmental conditions usually occurring in the spring probably will make the ½-inch plantings on this soil type the most desirable for all the crops tested in these studies.

The results in Table 6 are for the average emergence from Merrimac loamy fine sand.

The emergence from this soil type in the field was lower from the surface than from the ½-inch planting for all crops except alfalfa and Kentucky bluegrass, but the difference was not as great as with the Fargo silty clay loam. Reed canary grass gave only 51% emergence from the surface planting but 80% emergence from the ½-inch planting. Red clover, timothy, brome grass, crested wheat grass, and reed canary grass were the only crops to produce over 50% emergence from the 1-inch depth. Brome grass was the only crop in the field to give a satisfactory emergence from the 2-inch depth which was 63%. In the greenhouse the highest emergence was from the surface plantings. The 1-inch planting in the greenhouse showed over 50% stand only in the case of red clover, brome grass, reed canary grass, and crested wheat grass. In general, in no tests was the emergence of

TABLE 6.—*Percentage of total emergence from Merrimac loamy fine sand.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	74	73	44	4	0	79	52	30	0	0
Sweet clover	64	65	31	2	0	82	46	29	0	0
Red clover	74	81	64	0	0	80	80	59	0	0
Alsike clover	59	65	20	0	0	66	42	14	0	0
White clover	58	76	25	0	0	77	66	30	0	0
Timothy	52	80	56	0	0	79	67	48	0	0
Brome	82	99	91	63	16	100	97	94	80	32
Crested wheat	70	75	61	10	0	76	70	57	11	0
Reed canary	51	80	67	22	1	88	72	68	51	26
Kentucky blue	32	30	6	0	0	82	63	18	0	0

seedlings higher from this sandy soil than from the other soil types except from Clinton silt loam.

In Table 7 are given for each crop the average results of emergence for all soil types from each depth in order to compare only the differences shown by the crops.

TABLE 7.—*Summary of percentage of total emergence from all soil types.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	77	74	40	7	0	76	59	42	16	0
Sweet clover	64	62	30	4	1	65	45	34	8	0
Red clover	77	82	63	8	0	83	78	64	9	0
Alsike clover	65	69	27	0	0	71	49	33	0	0
White clover	71	76	34	0	0	84	69	49	0	0
Timothy	74	74	44	0	0	85	75	61	3	0
Brome	89	98	90	56	12	100	100	99	75	29
Crested wheat	76	75	52	6	1	83	74	64	15	1
Reed canary	62	80	68	27	3	92	83	76	52	19
Kentucky blue	41	41	5	0	0	83	61	23	0	0

The total emergence from the surface and from the ½-inch plantings was satisfactory for all crops in these averaged field tests. The only crop which showed a definitely lower emergence for the surface than for the ½-inch planting was reed canary grass. Red clover was the only legume in these studies which averaged more than 50% emergence from the 1-inch depth of planting. Brome grass and reed canary grass gave a satisfactory emergence at the 1-inch depth of planting, while crested wheat grass showed a fair emergence of 52%. From the 2-inch depth of planting only brome grass showed emergence greater than 50%. The summary of the total emergence in the greenhouse showed what might be expected in the field under ideal

conditions. Under the greenhouse conditions in these tests, plantings at the surface and ½-inch depths were satisfactory for all crops with red clover, brome grass, reed canary grass, and crested wheat grass producing good results from the 1-inch depth. Brome grass and reed canary grass showed over 50% emergence from the 2-inch plantings in the greenhouse.

After the above summaries had been obtained there appeared to be some correlation between emergence from the greater depths of planting and weight of seed. Since this association seemed to be rather constant for the emergence in the greenhouse and field, eight more grasses which were tested only in the greenhouse on all soil types were used in order to have a greater range of weight of seeds. In Table 8 are given the results of the correlation study between weight of seed for each crop and the average total emergence from the different depths in the greenhouse on all soil types.

TABLE 8.—*Correlation of seed weight with total emergence from five depths of planting.*

Crop	Weight in grams of 1,000 seeds	Percentage emergence in greenhouse at different depths				
		0	½ in.	1 in.	2 in.	3 in.
Alfalfa	2.17	76	59	42	16	0
Sweet clover	1.91	65	45	34	8	0
Red clover	1.62	83	78	64	9	0
Alsike clover	0.71	71	49	33	0	0
White clover	0.68	84	69	49	0	0
Sudan grass	9.64	79	63	57	51	47
Red Turghai millet	4.45	78	68	63	47	48
Brome grass	3.57	100	98	95	75	34
German millet	2.80	76	66	70	58	47
Slender wheat grass	2.45	93	92	88	69	33
Crested wheat grass	2.02	83	74	64	15	1
Perennial rye grass	1.93	99	96	96	87	69
Meadow fescue	1.58	94	89	81	52	13
Orchard grass	0.87	76	57	45	11	0
Reed canary grass	0.84	92	83	76	52	19
Timothy	0.41	85	75	61	3	0
Kentucky bluegrass	0.21	83	61	23	0	0
Redtop	0.11	80	60	38	0	0
D.F. = 16 Calculated r Significant r .4683		−.029	.057	.246	.473	.600

The correlation coefficient was considered significant when the odds were 19:1 or greater that this difference did not occur because of chance alone. As is shown by the correlation coefficients, the weight of seeds was a significant factor in determining emergence in these tests only when they were planted 2 or 3 inches deep. However, the relationship at these depths is not linear. Perennial rye grass and reed canary grass gave emergences which are higher than would be expected from their seed weights. Likewise, crested wheat grass showed emergences which were distinctly lower than would be expected.

Consequently, the emergence from these depths for all crops probably should be determined experimentally.

Additional results taken recently from greenhouse and field experiments showed that red top and orchard grass produced good stands only from the surface and ½-inch depths. Sudan grass, German millet, Red Turghai millet, slender wheat grass, meadow fescue, and perennial rye grass emerged satisfactorily from the surface, ½- and 1-inch plantings. Perennial rye grass, sudan grass, and the millets showed emergence as high as those for brome grass from the 2- and 3-inch plantings.

The results in Table 9 are given to compare the differences in total emergence from each depth from the different soil types as an average of all crops.

TABLE 9.—*Summary of average total emergence for all crops at each depth in each soil type.*

Soil type	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Carrington heavy silt loam	80	75	51	9	0	84	76	61	20	4
Clinton silt loam	82	71	35	6	1	77	57	41	7	1
Clarion silt loam	73	74	37	11	2	83	73	61	22	6
Fargo silty clay loam	52	74	57	18	6	86	74	64	25	8
Merrimac loamy fine sand	62	72	46	10	2	81	66	48	14	6

From Fargo silty clay loam and Merrimac loamy fine sand the total emergence in the field was definitely higher from the ½-inch than from the surface plantings.

In the field, the emergence from the surface plantings was high on Carrington heavy silt loam and on Clinton silt loam. Considering the 1-inch depth of planting only, the emergence was highest on Fargo silty clay loam in both the greenhouse and field tests and lowest on Clinton silt loam.

In the greenhouse the total emergence was highest from the surface planting on all soil types. The lowest percentage in the greenhouse at each depth was on Clinton silt loam. In general the decrease in emergence from the surface to the 3-inch depth of plantings in the greenhouse was fairly constant for each soil type which would be expected under optimum conditions.

Summary of the rate of emergence for each crop from each depth from each soil type is not given in detail as the mass of data was too great.

The rate of emergence was more uniform in the greenhouse than in the field. This difference was probably caused by the more variable environmental conditions in the field. The rate of emergence in the field was influenced more by environmental changes at the surface planting than at the deeper depths. From all depths in the field, the emergence was influenced greatly from day to day by temperature and moisture changes.

Reed canary grass emerged much more slowly on Fargo silty clay loam in the field than in the greenhouse. The rate of emergence of the grasses in the field was somewhat slower on the Fargo silty clay loam than on the other soil types. In the greenhouse, the clovers tended to emerge most rapidly from the Merrimac loamy fine sand.

The rate of emergence in the greenhouse was more rapid for all crops from the surface planting than from the other planting depths. In contrast to these results the rate of emergence in the field was most rapid for all crops from the ½-inch depths of planting. From the same depths, brome grass and crested wheat grass reach maximum emergence sooner than reed canary grass and Kentucky bluegrass. No important differences in the rate of emergence among the legumes were observed in either the field or greenhouse tests.

A summary of the rate of emergence is given in Table 10 to show the average differences as groups between the legumes and grasses used in these studies. For each depth the percentage of the total emergence was calculated for each five-day period.

TABLE 10.—*Percentages of average total emergence of legumes and of grasses from all soil types from each depth by five day-periods after planting.*

Days	Field experiments									
	Legumes					Grasses				
	0	½ in.	1 in.	2 in.	3 in.	0	½ in.	1 in.	2 in.	3 in.
5	—	9	3	—	—	—	—	—	—	—
10	49	62	71	47	—	15	44	48	10	—
15	49	27	21	47	—	58	47	45	63	47
20	2	2	4	6	—	19	7	6	24	47
25	—	—	1	—	—	7	2	1	3	6
30	—	—	—	—	—	1	—	—	—	—
Total emergence	70	74	38	3	—	68	73	51	17	3
Days	Greenhouse experiments									
	Legumes					Grasses				
	0	½ in.	1 in.	2 in.	3 in.	0	½ in.	1 in.	2 in.	3 in.
5	66	40	13	35	—	6	1	1	—	—
10	31	57	79	53	—	82	84	81	46	6
15	3	3	8	12	—	11	13	15	46	69
20	—	—	—	—	—	1	2	3	7	25
25	—	—	—	—	—	—	—	—	1	—
30	—	—	—	—	—	—	—	—	—	—
Total emergence	76	60	45	7	—	89	79	66	30	10

In the greenhouse tests the legume seedlings emerged much more rapidly than the grass seedlings. Even under the less favorable conditions in the field, the legume seedlings emerged more rapidly. In addition, the total emergence of the legumes was attained over a shorter

period of time than with the grasses. This ability to emerge more rapidly should be a distinct advantage to the legumes in the field as favorable conditions for emergence would not be necessary for so long a time after planting as with the grasses.

SUMMARY AND CONCLUSIONS

The purpose of the experiments was to determine the effect of depth of planting of seed and of soil type upon the initial stand of a number of grasses and legumes, the majority of which are used in the pastures and meadows of Minnesota.

A study was made of the total emergence of the grasses and legumes from five depths of planting in five soil types. The rate of emergence was also taken for the same variables.

The depth of planting was found to be the most important factor which determined the total emergence of seedlings of the individual crops in these studies. Approximately ½ inch was a satisfactory depth at which to plant the species used in these studies, although the surface planting produced good stands under ideal conditions for emergence.

Timothy and crested wheat grass produced optimum stands in the field from the ½-inch depth while the 1-inch depth of plantings was not very satisfactory, especially on Clinton silt loam. Reed canary grass planted 1 inch deep produced good emergence on all soil types. Satisfactory emergence was obtained for brome grass from the 2-inch depth of planting on all soil types except Clinton silt loam.

Alfalfa and sweet clover produced uncertain stands at the 1-inch depth of planting in the field on all soil types except Fargo silty clay loam. The emergence was satisfactory for red clover at the 1-inch depth on all soil types.

From these results, it appears that brome grass can be mixed and seeded with grain crops if no other satisfactory method of seeding is available.

The seed weight of 18 species of grasses and legumes tested in the greenhouse on all soil types showed a significant positive correlation with the total emergence from the 2- and 3-inch depth of plantings.

Surface plantings gave the highest percentage of emergence for all crops on Carrington heavy silt loam and on Clinton silt loam.

In the field the total emergence was definitely greater from the ½-inch plantings than from the surface plantings on the Fargo silty clay loam and Merrimac loamy fine sand.

The total emergence from the deeper depths of planting was somewhat higher on Fargo silty clay loam than on the other soils and was lowest on Clinton silt loam.

If the depth of planting which gives the maximum total emergence is used for a given species, it should be possible to obtain a desirable stand by planting less seed per acre than has been practiced by farmers and often recommended by agronomists.

Environmental conditions were found to influence the rate of emergence in these studies more than the other variables. The emergence was nearly complete 15 days after planting for all species studied.

The legumes reached maximum emergence approximately five days before the grasses. These data indicate that desirable conditions for emergence must continue somewhat longer after planting for the grasses than for the legumes.

LITERATURE CITED

1. KIRK, L. E., STEVENSON, T. M., and CLARKE, S. E. Crested wheat grass. Dom. of Canada Dept. Agr. Pamphlet 157. New Series. 1934.
2. LOVE, L. D., and HANSON, H. C. Life history and habits of crested wheat grass. Jour. Agr. Res., 45:371–383. 1932.
3. McMICHAEL, S. C. The relation between depth of seeding and emergence for certain grasses. Soil Conservation Service, Huron, South Dakota. (Unpublished.) 1934.
4. STEVENSON, T. M. Sweet clover in Saskatchewan. Univ. of Sask. Agr. Ext. Bul. 9. 1938.

DETERMINING BY PLANT RESPONSE THE RETENTION OF NUTRIENT IONS BY SOILS[1]

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THE retention[3] or non-retention of ions or compounds bearing essential elements have until now been largely determined by the procedures of analytical chemistry. We may logically reason from experimental data so obtained that retention should often be reflected in plant response in the field. To demonstrate retention by plant growth—primarily to make the teaching of this subject more concrete and more appealing—was the object of the writers in starting this study. With the general validity of the method evaluated by the data contained herein, and other similar data, the senior writer has continued to use it as a research procedure in investigating the reactions of a number of nutrient-containing compounds with several soils. The results of these studies will appear later.

A method for poisonous substances worked out by Crafts[4] was first tried. By allowing a solution containing a toxic material to drip slowly upon a continuous column of dry soil in a demountable tube, he studied the retention in the various levels of the column. After each column was wet to the bottom, it was sectioned transversely with the successive sections being placed in a series of cannery tins and subsequently cropped to oats. Retention was judged by the injury to the oats.

In preliminary trials with this method $NaNO_3$, NH_4OH, and $(NH_4)_2SO_4$ were used as test solutions. Plant response to the nitrogen contained therein demonstrated the non-retention of NO_3 ions, while the NH_4 ions were all retained in the very uppermost section of each of the respective soil columns. After these trials, a simplification of the procedure seemed desirable and at the same time possible without materially altering the results. In this simplification the writers have used an interrupted column of soil namely, a stack of pots, the drainage from the hole of one dripping down into the one below. This procedure introduces one more condition that makes it different from field conditions, but it has manifold manipulative advantages. Fig. 1 gives the main features of the procedure.

In comparing the two methods, it is evident that practically all of the operations in handling the discontinuous column of pots are necessary, also, in the continuous column of soil with the further disadvantage that in the latter case these must be carried on with wet soil instead of dry. A great number of other manipulations, necessary with the continuous column, are not required in the column of pots.

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication October 11, 1938.

[2]Lecturer in Agronomy and Senior student (1937), respectively.

[3]Way (as quoted by Russell: Soil Conditions and Plant Growth) used "retention" where the word "fixation" is now often used. We have followed Way's example to prevent possible confusion from the use of "fixation of nitrogen" as this term has been preempted for an entirely different concept.

[4]CRAFTS, A. S. The toxicity of sodium arsenite and sodium chlorate in four California soils. Hilgardia, 9:461–498. 1935.

Presenting the subject of ionic exchange in soils to two college classes and the subject of the interaction of soils and fertilizers to a large group of farmers has been greatly aided by the use of illustrative material of this kind. Principles discovered by Way in the laboratory in 1850 may thus be demonstrated by plant response.

PROCEDURE

The general procedure is shown in Fig. 1 and more of the details of weighing and other data in Table 1. Four-inch pots and cannery tins (No. 2½) were previously prepared for the columns and for subsequent growth by painting with asphaltum paint or varnish. Cannery-tin tops previously punched with large holes are used to hold the pots in the column apart (Fig. 1 lower left). A square of waxed paper with a little of the soil under one side is used to cover the hole in the pot.

Pots (5-inch likewise painted) equipped with needle-valves, each consisting of a one-holed rubber stopper plugged with a piece of glass tubing drawn to a long taper, act as reservoirs for the test solutions. The amount of solution in the reservoir sufficient to wet all of the soil in the column with a safe excess is increased accordingly if confirmatory analyses are to be made on the drainage water. The rate of dripping is regulated by raising or lowering the tapered tubing and is kept slow enough to prevent any but a little accumulation on top of the soil. After dripping is completed and the excess allowed to drain away, the columns are taken down and each pot is nested into its respective drainage tin. The drainage water at the bottom of the column is measured and discarded or saved for analysis. Often the weighings of pots (Table 1—d, e, f, g) are omitted but not the measuring of the drainage water.

TABLE 1.—*Some details of procedure and data recorded for Fig. 1 and Table 2.*

Date of Percolation: *March 11, 1938* — Crop: *Double Dwarf milo*
Planted: *March 19, 1938* — Randomized: *March 28, 1938*
Harvested: *April 20, 1938* — Water: *Tap*

Column No. and treatment (a)	Pot No. (b)	No. in Col. (c)	Percolation pot weights, grams: Tare pot (d)	With soil: Dry (e)	With soil: Wet (f)	Grams H_2O retained (g)	Harvest: Height, cms (h)	Harvest: Wet weight, grams (i)	Harvest: Dry weight, grams (j)
1. H_2O	793	1	323	723	871	148	21.7	1.59	0.37
	794	2	324	724	863	139	22.5	1.61	0.36
	795	3	338	738	865	127	20.4	1.37	0.32
				Drainage ml		9			
450 ml added				Recovered		423			
8. $(NH_4)_2SO_4$	814	1	336	736	883	147	73.8	54.12	6.85
	815	2	340	740	876	136	19.0	1.28	0.32
	816	3	342	742	869	127	21.7	1.23	0.29
				Drainage ml		22			
450 ml added				Recovered		432			

Any screened and well-mixed lot of dry soil deficient in the nutrient element to be tested may be used, though a preliminary trial to determine how rapidly water moves through it helps to eliminate impervious soils. One silt loam and a fine sandy loam out of 14 different lots of soil have given difficulties of this kind. If a soil is deficient in more than one element, those not under test must be sup-

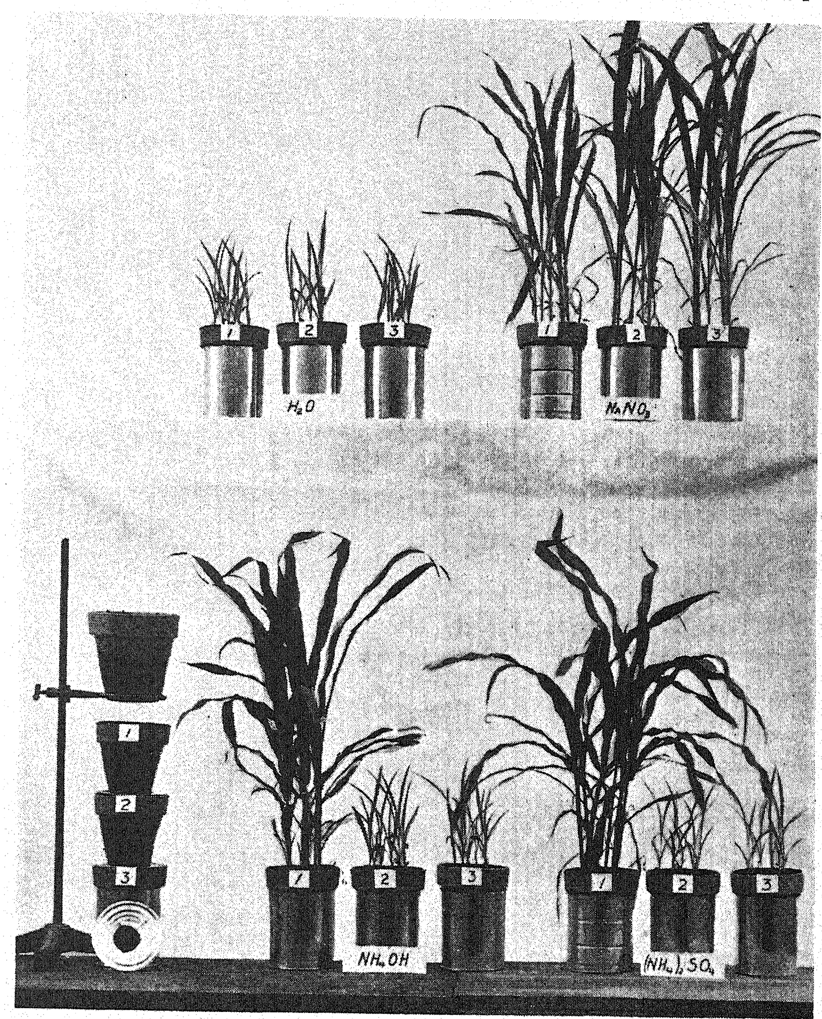

FIG. 1.—NITROGEN-RETENTION FROM PERCOLATING SOLUTIONS. *Method (lower left)*: The percolating solution being tested, slowly drips from the larger (5 inch) pot at the top, down upon the column of three 4-inch pots (1, 2, and 3) each containing 400 grams of dry soil deficient in nitrogen and planted to milo. The milo is allowed to grow about one month after the columns are taken down. *Results (above)*: The test solution used in each case is shown on the card leaning against pot No. 2 of that column. Thus the NO_3-ions of $NaNO_3$ are not retained by the soil, while the NH_4-ions of both NH_4OH and $(NH_4)_2SO_4$ are retained.

plied either as relatively insoluble or readily retained compound, e.g., K_3PO_4 for the soil in Table 2, added before percolation, or as a soluble and not readily retained compound, as urea or nitrates for Aiken and Huer Huero soils in Table 3, added in equal amount to each pot of a given test.

If the soil is light and the solutions to be used are not toxic, large seeds may be planted in the dry soil before percolation. This procedure saves considerable time and in a month's growth the short difference of time between wetting the seed in the top pot and in the lowest one is of no consequence practically. Ten seeds of milo per pot are usually planted. As soon as practicable these are usually thinned to six. Because of its very erect growth in the greenhouse, milo has been used as a test plant and has given satisfactory to marked responses to N, P, and S in pot cultures.

A pot with its drainage can serve much the same purpose as a Mitscherlich pot, as the drainage water is periodically returned to the pot. Excess waterlogging in all but impervious soils can be avoided by judicious watering, but the extreme care necessary with closed containers is not necessary.

EXPERIMENTAL RESULTS

Table 2 shows the results secured with various N compounds on Yolo fine sand. The percolating solutions contained 30 milligram-atoms of nitrogen for each column of three pots. Milo was seeded in the dry soil before percolation. Many of these solutions were toxic to the first crop, as shown in Table 2, by the description of the growth after 8 days. In some cases the place of maximum retention coincided with the location of the seed. For the second planting the soil was

TABLE 2.—*Retention of the nitrogen of various percolating solutions by Yolo fine sand in a column of 4-inch pots as shown by the subsequent yields of milo, each yield figure being the average of three cultures.*

Pot No.*	1st planting, 8-day growth†	2nd planting, 32-day growth: Green weight, grams	2nd planting, 32-day growth: Dry weight, grams	1st planting, 8-day growth†	2nd planting, 32-day growth: Green weight, grams	2nd planting, 32-day growth: Dry weight, grams	1st planting, 8-day growth†	2nd planting, 32-day growth: Green weight, grams	2nd planting, 32-day growth: Dry weight, grams
	NH_4OH			$(NH_4)_2SO_4$			Gelatin		
1, top	O	43.4	6.04	SS	48.7	6.41	G	36.0	6.02
2, middle	G	2.0	0.42	G	1.5	0.32	G	1.6	.37
3, bottom	G	1.7	0.38	G	1.2	0.30	G	1.4	.31
Control		20.3	3.34		26.6	4.12		14.0	2.49
	$NaNO_3$			$NaNO_2$			Distilled water		
1, top	S	14.7	2.53	O	14.3	2.61	G	1.6	0.35
2, middle	G	24.4	4.14	O	18.5	3.25	G	1.6	0.35
3, bottom	G	21.7	3.74	O	19.7	3.45	G	1.7	0.38
Control		19.2	3.60		15.4	2.68		1.7	0.36

*Order of pots in the column during percolation. Control received ⅓ the volume of the same solution as added to the top of the percolating column.

†For 8 day growth of 1st planting, G = good, SS = slightly stunted, S = stunted, and O = no growth.

inverted in each pot and replanted. Table 2 likewise gives the resulting yields after 32 days.

The distilled water shows a tendency for some nutrient element (probably N as nitrate) to be leached down to the bottom pot. Both plantings show that the nitrogen of NH_4OH is retained by the soil in the top pot; in the first planting by the toxic condition and in the second by the increased growth. The retention of the NH_4 ion of the ammonium sulfate is likewise shown in the yields from the top pot. The nitrogen of the protein, gelatin, is retained in the top pot. The mechanism responsible is not fully evident. Gelatin considered as a colloid dispersed in water would, however, be filtered out of suspension by the soil. The NO_3 ions are not retained but apparently enough Na ions are retained by this light soil to bring about a condition less than optimum in the top pot.

With $NaNO_2$ the uniformly toxic condition in the first planting and the rather uniformly good growth of the second show that the NO_2 ions are not retained by the soil. In the intervening 8 days between the two plantings, the nitrite would have time to change more or less completely to the corresponding nitrate.

Tests for the retention of the various elements have been made with various compounds and with different soils deficient in the elements in question during the last year and a half. The more interesting of these are reported in Table 3. The Yolo silt loam retains the NH_4 ions of NH_4NO_3 while the NO_3 ions are not retained.

TABLE 3.—*Retention of the nitrogen, phosphorus, or sulfur of percolating solutions by various soils as shown by the growth of milo.**

Soil	Yolo silt loam		Aiken loam		Huer Huero sandy loam	
Percolating solution	H_2O	NH_4NO_3	H_2O	Na_2HPO_4	H_2O	Na_2SO_4
Order of pots in column:						
1, top	0.22	1.47	0.84	3.61	0.31	3.22
2, middle	0.19	0.83	0.81	0.77	0.27	2.62
3, bottom	0.17	0.88	0.89	0.76	0.60	3.28

*Yields of dry matter in grams per pot, average of triplicate cultures.

Nearly every annual crop markedly responds to phosphate applications on Aiken loam. In the case reported in Table 3 the percolating solution contained 1.5 milligram-atoms of P for the column of three pots. In the early stages of growth a total of 9 milligram-atoms of nitrogen as $Ca(NO_3)_2$ and urea was added to each pot in this test as this soil is also N-deficient.

The Huer Huero sandy loam, a S-deficient soil, shows no or incomplete retention of the sulfate ion. It is interesting to note that with the distilled water percolated through this soil the bottom pot of this column gave the highest yield, indicating that some S-containing substance had been carried down, probably traces of sulfate leached down. In this case a total of 8 milligram-atoms of N as urea was added

to each pot in the series after growth had started. The sulfate was added at the rate of 1.5 milligram-atoms of S per column.

These results are inconclusive in determining whether the sulfate ion might have been slightly retained by this soil as insufficient N was added to make S the limiting element in the Na_2SO_4 column.

SUMMARY

1. A method is described (Fig. 1) whereby the retention or non-retention of nutrient ions or compounds from percolating solutions by the soil may be shown by plant response. The illustrative material so produced has been a material aid in the presentation of the subjects of ionic exchange and the interaction between fertilizers and soils to students and farmers.

2. The retention of ammonium ions from various ammonium compounds and of phosphate ions demonstrated by plant growth are in agreement with current analytical data as is the non-retention of nitrates, nitrites, and sulfates. Gelatin as a colloid is probably filtered out of the percolating solution by the soil.

3. The method shows promise as a research tool, useful in extending our knowledge of the interaction of various ions and compounds with soils.

INHERITANCE OF RESISTANCE TO LEAF RUST IN COMMON WHEAT[1]

WILLIAM EUGENIUS ADAMS[2]

THIS is a study of the inheritance of leaf rust of wheat, *Puccinia triticina*, Erikss., in crosses between Hope, a resistant variety, with Leap's Prolific, Fulcaster, and Purplestraw, the three leading varieties in North Carolina.

It has long been known that leaf rust of wheat is in many seasons a factor of considerable importance in the production of wheat, especially in the soft red winter wheat areas and particularly in the southeastern states.

Apparently very little work has been done on varieties of wheat adapted to North Carolina. Mains, Leighty, and Johnston[3] made an intensive study of western wheat varieties and drew the following conclusions: In a resistant Kanred cross with several susceptible varieties Kanred resistance may depend upon several factors. In crosses with resistant Malakoff and susceptible varieties in the seedling stage showed Malakoff resistance dependent upon a main dominant genetic factor. In the F_2 there were 3 resistant: 1 susceptible. In other crosses with susceptible Malakoff and Webster a 1:2:1 ratio occurred and resistance appeared to be dependent upon a single main factor difference. In a resistant Fulcaster crossed with susceptible Kanred to physiologic form 9, resistance was dependent upon a single main factor difference. In a Malakoff×C. I. 3778 and Norka× C. I. 3756, the 9:3:3:1 ratio indicated the resistance of each parent dependent upon a single independently inherited factor.

DESCRIPTION OF MATERIAL

The materials used in this study were Leap's Prolific, Fulcaster, and Purplestraw, the three leading soft red winter wheat varieties in North Carolina, all well adapted to the conditions in the state, but not very resistant to leaf rust. Hope,[4] the resistant parent, is a hard red spring wheat of no commercial importance. It has, however, been found valuable as a resistant parent in crosses.

The seed of Hope were furnished by Dr. R. W. Caldwell and J. Allen Clark, Bureau of Plant Industry, U. S. Dept. of Agriculture. The seed for the susceptible parents, Leap's Prolific, Fulcaster, and Purplestraw, were obtained from the Piedmont Branch Station, Statesville, North Carolina.

[1]Presented as a thesis to the Department of Agronomy of the North Carolina State College of Agriculture and Engineering of the University of North Carolina in partial fulfillment of the requirements for the degree of master of science. Received for publication October 15, 1938.

[2]Formerly Reserach Assistant in Agronomy at North Carolina Agricultural Experiment Station; now Junior Agronomist, Soil Conservation Service, U. S. D. A., Franklinton, North Carolina. Acknowledgment is due Dr. J. B. Cotner for supplying the material for the study and for his advice and directions of the work.

[3]MAINS, E. B., LEIGHTY, C. E., and JOHNSTON, C. O. Inheritance of resistance to leaf rust, *P. triticina*, in crosses of common wheat, *T. vulgare*. Jour. Agr. Res., 33:931. 1926.

[4]CLARK, J. ALLEN, MARTIN, JOHN M., and BALL, CARLETON, R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.
CLARK, J. ALLEN. Correspondence, February 25, 1935.

METHOD OF PROCEDURE

Crosses of Hope with Leap's Prolific, Fulcaster, and Purplestraw were made as follows: (1) Leap×Hope, (2) Hope×Leap's Prolific, (3) Hope×Fulcaster, and (4) Purplestraw×Hope.

The parents and first generation hybrids were planted in the field at Raleigh, North Carolina, October, 1932. The parents were also planted again with the F_2 and F_3 material in October, 1933 and 1934, respectively. The F_2 and F_3 material were grown at both Raleigh and Statesville, North Carolina.

In the field nurseries at Raleigh and Statesville the infection of the parents and hybrids resulted from the rust naturally occurring in these localities. In most instances, leaf rust was so abundant that susceptible varieties were heavily infected and a very good test of reaction to the rust was obtained. Under such conditions it was impossible to control the physiologic forms of rust by which the hybrids were infected.

In taking notes upon hybrids in the field nurseries, infection was determined, according to the scale used by the Office of Cereal Investigations, U. S. Dept. of Agriculture[5] by which it is estimated in percentages the number of uredenia actually formed compared with the number possible. Notes were taken when infection had reached its maximum development. The plants were classified according to the types of infection which developed. Seven different classes of rust infection were recognized, based upon the degree of the infection.

RESULTS OBTAINED

Table 1 gives the comparative susceptibility and resistance of parents and F_2 plants. In 1934 and 1935, 76 and 87% respectively, of the Hope plants showed less than 1% of rust infection. No plants

TABLE 1.—*Reaction of parent varieties and F_2 plants grown at Statesville in 1934.*

Variety or cross	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
Hope	8	43	12	4	—	—	—
Leap's Prolific	—	—	—	—	16	48	64
Fulcaster	—	—	4	16	23	3	—
Purplestraw	—	—	—	—	12	25	15
Hope×Leap's Prolific F_2	—	9	18	31	12	1	—
Leap's Prolific×Hope F_2	—	—	2	19	22	19	6
Purplestraw×Hope F_2	—	24	34	43	10	—	—
Hope×Fulcaster F_2	—	28	85	46	2	—	—

showed more than 25% infection. Leap's Prolific, apparently highly susceptible, showed all plants above 25% infection, with 87% of those grown in 1937 and 40% of those grown in 1935 above 75% infection. Purplestraw was all above 25% infection, with 50% of the plants grown each year in the 50 to 75% class. Fulcaster, apparently less susceptible than Leap's Prolific and Purplestraw, showed a few plants in the 1 to 4% class, 50% in the 25 to 50% class, and no plants showing more than 75% infection in 1934. In 1935, 50% of the plants were in the 50 to 75% class.

[5]See footnote 3.

The F_1 showed very little infection. This was apparently due to either a small amount of inoculum or unfavorable weather conditions for the development of spores, or both.

The Hope×Leap's Prolific F_2 (Figs. 1 and 2) gave immune, intermediate, and susceptible plants with 81% below 25% infection, and nine plants less than 1% infection. In the reciprocal F_2 cross, Leap×Hope, did not show quite as much resistance with 63% below 50% infection and 31% in the 25 to 50% class. Two plants were in the 1 to 4% class. The Purplestraw×Hope F_2 (Fig. 3) showed no plants

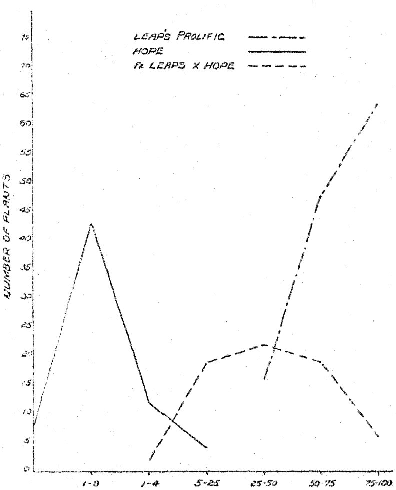

FIG. 1.

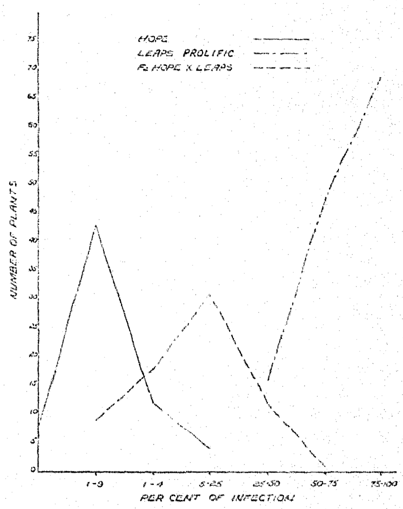

FIG. 2.

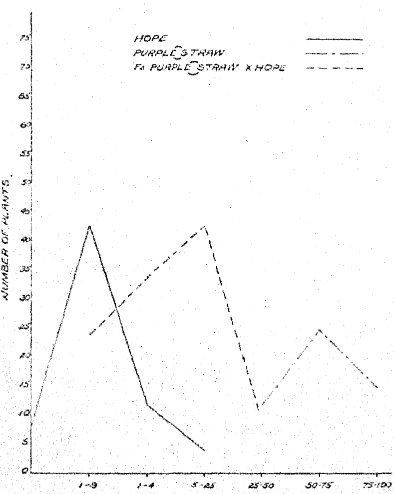

FIG. 3.

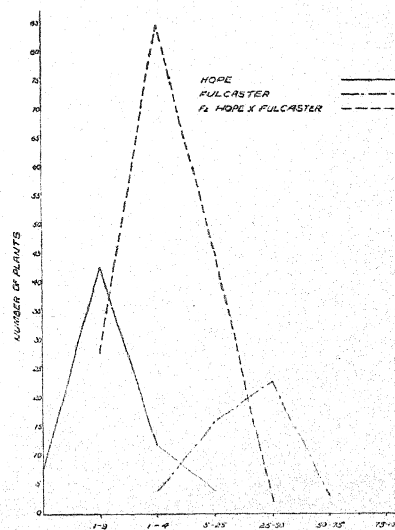

FIG. 4.

above 50% infection, with 91% below 25% and 27% under 5% infection. The Hope×Fulcaster F_2 (Fig. 4) showed more resistance than any of the crosses. There were 70% of the plants less than 4% and all plants less than 50% infection.

The Purplestraw×Hope F_3 (Table 2), showed four rows under 1%, six rows intermediate, and three rows rather highly infected.

TABLE 2.—*Purplestraw×Hope (F_3), 1935.*

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
1080	11	4	–	–	–	–	–
1081	8	6	–	–	–	–	–
1082	–	1	3	6	4	1	–
1085	–	3	2	3	5	1	–
1103	12	1	–	–	–	–	–
1104	13	–	–	–	–	–	–
1107	–	–	–	–	8	3	4
1154	1	3	3	2	4	2	1
1155	3	2	3	1	2	3	1
1158	1	2	3	1	2	1	–
1159	1	1	2	2	3	1	–
1160	5	6	3	–	–	–	–
1161	4	7	5	–	–	–	–
1164	–	–	–	–	5	6	3
1165	–	–	–	–	3	8	4
1172	8	6	1	–	–	–	–
1173	6	5	2	–	–	–	–

*Rows above 1,150 grown at Raleigh; others grown at Statesville.

The Hope×Fulcaster F_3 (Table 3), showed three rows under 1%, five intermediate rows, and three rows above 50% infected.

TABLE 3.—*Hope×Fulcaster (F_3), 1935.*

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
2619	–	–	2	3	2	3	–
2630	2	3	1	–	–	–	–
2631	2	6	–	–	–	–	–
2632	–	3	4	3	2	2	–
2901	7	9	–	–	–	–	–
2902	7	6	–	–	–	–	–
2904	2	4	6	4	1	1	–
2905	1	6	5	3	1	1	–
2906	1	7	4	3	2	1	1
2913	–	–	–	–	2	5	6
2914	–	–	–	–	4	3	1
2915	–	–	–	–	2	3	4

*Rows in 2,600 group grown at Statesville; rows in 2,900 group grown at Raleigh.

In the Hope×Leap's Prolific F_3 (Table 5) there were six resistant rows with the majority of the plants with no infection, five intermedi-

ate rows, and four rows showing greater than 50% infection. The reciprocal Leap's Prolific×Hope F_3 (Table 4), indicated similar results, with five rows under 1% infection, five intermediate rows, and three rows with all plants above 50% infection.

TABLE 4.—*Leap's Prolific×Hope* (F_3), *1935*.

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
1541	–	–	–	–	4	7	1
1542	–	–	–	–	–	9	6
1543	9	7	–	–	–	–	–
1544	7	8	–	–	–	–	–
1545	2	3	3	4	2	2	1
1546	–	1	3	8	1	2	1
1549	–	2	7	4	3	2	–
1550	8	7	–	–	–	–	–
2047	–	–	–	–	–	9	6
2048	–	–	–	–	–	10	4
2084	–	2	5	6	3	1	1
2085	1	1	3	5	3	1	2
2086	6	7	–	–	–	–	–
2087	8	6	–	–	–	–	–

*Rows in 1,500 group grown at Statesville; rows in 2,000 group grown at Raleigh.

TABLE 5.—*Hope×Leap's Prolific* (F_3), *1935*.

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
1727	11	2	–	–	–	–	–
1728	7	6	–	–	–	–	–
1730	–	–	–	–	–	8	5
1731	–	2	3	6	7	2	–
1732	–	–	–	–	–	7	8
2428	7	4	–	–	–	–	–
2430	1	2	2	3	2	2	1
2433	1	2	1	3	6	3	1
2435	1	1	2	2	3	4	1
2436	–	1	5	3	5	3	1
2437	6	4	–	–	–	–	–
2438	7	3	–	–	–	–	–
2439	4	5	–	–	–	–	–
2440	5	3	2	–	–	–	–
2523	–	–	–	–	–	5	4
2526	–	–	–	–	1	3	4
2581	–	–	–	–	–	6	5

*Rows in 1,700 group grown at Statesville; rows in 2,400 and 2,500 groups grown at Raleigh.

In these trials the results are complicated by varying conditions of soil, climate, time of maturity, and mixtures of physiologic forms and an accurate determination of the facts of inheritance is difficult. The results would seem to indicate that resistance to leaf rust of wheat is

inherited, since the F_2 showed plants which were resistant, intermediate, and susceptible. The F_3 gave highly resistant rows, intermediate rows, and highly susceptible rows. In the F_3, families were obtained in each cross which showed less than 5% infection.

SUMMARY

Hope, a variety resistant to leaf rust of wheat, *Puccinia triticina*, Erikss., was crossed with Leap's Prolific, Fulcaster, and Purplestraw, susceptible varieties, with the following results:

1. The F_1 showed very little infection, apparently due to a small amount of inoculum or unfavorable weather conditions for this development.
2. The F_2 showed plants which were resistant, intermediate, and susceptible.
3. The Hope×Leap's Prolific F_2 showed 81% of the plants below 25% infection. The reciprocal cross, Leap's Prolific×Hope F_2, gave similar results.
4. The Purplestraw×Hope F_2 showed 91% of the plants below 25% infection.
5. The Hope×Fulcaster F_2, showing greater resistance than any of the crosses, gave 70% of the plants below 4% infection.
6. The F_3 gave rows which were highly resistant, intermediate rows, and also highly susceptible rows. F_3 families were obtained in each cross which showed less than 5% infection.

AN UNUSUAL ALKALI SOIL[1]

W. P. KELLEY AND S. M. BROWN[2]

PRELIMINARY tests made several years ago on an alkali soil sent to us by Professor W. W. Johnston of the Oregon Agricultural College, gave results which suggested that this soil probably contains a significant amount of some soluble alkaline substance other than carbonate and bicarbonate. For instance, it was found that the amount of standard acid required to titrate a water extract of this soil with phenolphthalein as indicator was considerably more than half that required with methyl orange.

As is well known, two steps are involved in the neutralization of normal carbonate. First, its conversion into bicarbonate, and second, the conversion of bicarbonate into CO_2 and H_2O. These reactions are illustrated by the following equations:

$$\text{(a)}\quad 2Na_2CO_3 + H_2SO_4 \rightleftarrows 2NaHCO_3 + Na_2SO_4$$

$$\text{(b)}\quad 2NaHCO_3 + H_2SO_4 \rightleftarrows 2CO_2 + 2H_2O + Na_2SO_4$$

The completion of reaction (a) corresponds to the phenolphthalein end point, whereas that of reaction (b) represents the end point with methyl orange, equal quantities of acid being neutralized in both steps of the reaction. Since reactions (a) and (b) are both included in the methyl orange titration, the amount of acid required with this indicator is just twice that required with phenolphthalein. We found, however, that in the titration of a water extract of this soil, the latter was considerably more than one-half that of the former. Ordinarily, the phenolphthalein titration of soil extracts requires considerably less than half as much acid as the methyl orange titration, which, of course, indicates that these extracts contain bicarbonate.

Accordingly, a more critical study of this soil has recently been made. The soil in question was taken from the upper 4 inches of virgin alkali land adjacent to the area on which the Oregon Agricultural College has conducted alkali reclamation experiments for many years (1, 5).[3] According to a statement sent to us by Professor Johnston, this soil was quite similar to that on which the reclamation experiments were located. In 1934, Wursten and Powers (5) reported that the virgin soil near these experiments contains considerable normal carbonate but no bicarbonate.

A water extract was prepared by shaking to approximate equilibrium 400 grams of the air-dried soil with 2,000 cc distilled water, then filtering through a Chamberland-Pasteur filter. Again it was found that the phenolphthalein titration required considerably more than half as much acid as the methyl orange titration. Accordingly, complete chemical analysis of the extract was made including Cl, SO_4, NO_3, PO_4, carbonate CO_2, SiO_2, Ca, Mg, K, Na, and pH.

[1]Contribution from the Citrus Experiment Station, University of California, Riverside, Calif. Received for publication October 17, 1938.

[2]Agricultural Chemist and Assistant Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 43.

Table 1 shows the analytical results expressed on the basis of 1 liter of the extract. It was found that the solution contained an unusually large amount of SiO_2 in addition to substantial amounts of CO_3, Cl, SO_4, and small amounts of NO_3 and PO_4. The principal base was Na. In view of the fact that the solution was brown-colored and contained a complex series of constituents, an electrometric titration was made using the glass electrode. The data, when plotted, showed two deflections in the curve, the first at about pH 8.5 and second at about pH 5.5, which corresponded roughly to the phenolphthalein and methyl orange end points, respectively. The amounts of acid required to produce these changes in pH were also approximately the same as in the colorimetric titrations.

TABLE 1.—*Analysis of 1 to 5 water extract of Vale, Oregon, alkali soil.*

Acid titration		Milligrams per liter										
Phenolphthalein (cc N/10 acid per 1,000 cc)	Methyl orange (cc N/10 acid per 1,000 cc)	Cl	SO_4	NO_3	PO_4	SiO_2	Carbonate CO_2	Ca	Mg	K	Na	pH
133.5	226.7	291.4	874.6	4.7	20.6	374.9	255	4	Trace	144.3	1231.5	10.75

Since the water extract was strongly alkaline (pH 10.75) and also contained substantial amounts of dissolved SiO_2, it is reasonable to conclude that sodium silicate was present in the solution. In view of the fact that, at the concentration and pH of the original solution practically all carbonate must have existed in the form of normal carbonate, it is concluded that this soil extract contained Na_2CO_3, Na_2SiO_3, NaCl, Na_2SO_4, and smaller amounts of $NaNO_3$ and Na_2HPO_4.

The several ions expressed as milliequivalents per liter ar e shown in Table 2. In making the calculations it was assumed that all the SiO_2 and carbonate CO_2 occurred in the solution as SiO_3 and CO_3 ions, respectively. As thus calculated, the total cations exceeded the total anions by 6.4 milliequivalents per liter. This suggests that a part of the sodium was present either in organic combination, which seems quite probable in view of the dark brown color of the solution, or that NaOH was present in significant amounts. It should be recalled that so-called sodium silicate commonly contains a greater amount of Na than is required by the formula Na_2SiO_3.

TABLE 2.—*Water-soluble ions expressed as milliequivalents per liter.*

Cl	SO_4	CO_3	SiO_3	NO_3	HPO_4	Total anions	Ca	Mg	K	Na	Total cations
8.2	18.2	11.6	12.5	0.08	0.4	50.98	0.2	Trace	3.7	53.5	57.4

The preceding discussion has dealt with a 1 to 5 water extract of this soil. In view of the data recently published by McGeorge (3, 4) and Keaton (2), it is probable that the pH of this soil under field moisture conditions is substantially lower than that of a 1 to 5 water extract. If so, the equilibrium between CO_3 and HCO_3 would be shifted in the direction of increased HCO_3. Therefore, in the open field, it is possible that this soil contains both HCO_3 and CO_3 in significant amounts. At about pH 10.4 and with the total amount of CO_2 found, there should be approximately two equivalents of CO_3 to one equivalent of HCO_3, and as the pH is lowered still further, HCO_3 will increase at the expense of CO_3 until at about pH 8.5 practically all CO_3 will be converted into HCO_3.

The exceptional feature of this soil is that it contains a substantial amount of sodium silicate in addition to soluble carbonate and the other salts common to alkali soils. Although it is common to find soluble SiO_2 in black alkali soils, the amount is usually small. This Oregon soil, however, contains relatively much soluble silica. Therefore, the geological and pedological history of this soil is a matter of some interest.

LITERATURE CITED

1. JOHNSTON, W. W., and POWERS, W. L. A progress report of alkali land reclamation investigations in eastern Oregon. Ore. Agr. Exp. Sta. Bul. 210. 1924.
2. KEATON, C. M. A theory explaining the relation of soil-water ratios to pH values. Soil Science, 46:259–265. 1938.
3. McGEORGE, W. T. Report on hydrogen-ion concentration of alkali soils. Jour. Assoc. Off. Agr. Chem., 20:220–221. 1937.
4. ———. The determination of soil reaction under field conditions by means of the spear-type glass electrode. Jour. Amer. Soc. Agron., 29:841–844. 1937.
5. WURSTEN, J. L., and POWERS, W. L. Reclamation of virgin black alkali soils. Jour. Amer. Soc. Agron., 26:752–762. 1934.

LEACHING STUDIES WITH VARIOUS SOURCES OF NITROGEN[1]

NELS BENSON AND R. M. BARNETTE[2]

BECAUSE of the open texture and ready penetration of water into many Florida soils, one of the most difficult problems in their management is the serious losses to which their soluble plant food components are exposed by direct leaching. This is especially true of nitrogen and accounts largely for the constant attention required to maintain in such soils an adequate balance of this element for nonleguminous plants.

If a soluble form of nitrogen could be found, therefore, that is consistently more stable in such soils and not so easily leached, obviously it would find a wide application under Florida conditions. The principal purpose of this paper is to present the results of a study of the stability against leaching of nitrogen in a number of fertilizer materials.

REVIEW OF LITERATURE

The loss of nitrogen from soils through leaching has been reported by many investigators (2, 4, 5, 6, 7, 12, and others).[3] Nitrate nitrogen is the main constituent lost, although other forms may leach to a lesser extent.

In some of these investigations fallow lysimeters have been treated with nitrogenous fertilizers and the leachings studied through definite periods varying from a few months to several years. These studies have shown almost complete recovery of nitrogen from applications of the nitrate form, most of which leached shortly following its application. Urea has been transformed to nitrate and efficiently leached in that form. Sulfate of ammonia has been nitrified to a slightly lesser extent than urea as indicated by a lower leaching of nitrate nitrogen. The insoluble organic fertilizers, on the other hand, have not been recovered very efficiently in the leachates.

Ammonium nitrogen has been reported to wash from light-textured soils when leaching took place shortly after the application of ammonium sulfate. The extent of the leaching has been found to vary directly with the base exchange capacity of the soil.

Parker (8) rated the retention of nitrogen sources by the soil as follows: Sodium nitrate, readily leached; urea, ammonium sulfate, and insoluble organics, leached with difficulty.

A study was undertaken to determine the relative leachability of different forms of nitrogen—nitrate, ammonium, nitrite, and urea—at various intervals following the application of nitrogenous materials to Norfolk sand. The leaching of nitrogen from this soil was further compared with other soils of different colloid content and properties.

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[1]Submitted in partial fulfillment of the requirements for the degree of master of science from the University of Florida. Contribution from the Department of Chemistry and Soils, University of Florida Agricultural Experiment Station, Gainesville, Fla. Published with the approval of the Director. Received for publication October 20, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 53.

SOILS USED IN THE WORK

In selecting soils for the study it was desired that a certain variation in texture and colloid content be involved; also that their distribution and economic importance be considered. Accordingly the following types were selected:

1. A Norfolk sand was obtained from a cultivated field at Gainesville, Florida. It is a well-drained soil having the following profile characteristics: Six inches of dark yellowish gray surface sand underlain by pale yellow sand.

2. A Bladen fine sand was obtained from a cultivated field near Hastings, Florida. The surface 8 inches consists of dark gray fine sand below which is a lighter gray fine sand to a depth of 30 inches, which changes abruptly to a heavy yellow sand and clay mixture mottled with gray, blue, and white. It is a poorly drained soil.

3. A Fellowship fine sandy loam was obtained from a virgin area west of Gainesville. The surface 8 inches is a dark yellowish brown fine sand grading into a lighter brownish yellow loamy fine sand with a slight crumb structure, becoming heavier at increasing depths to 20 inches where it changes rather abruptly into a very heavy yellow clay overlying limestone. Fragments of limestone and chert lie on top of the soil and are distributed throughout the profile. This soil type, although high and undulating, is considered to be poorly drained because of the impervious clay a short distance below the surface.

4. A Norfolk fine sandy loam was obtained from a virgin area at Graceville, Florida. The upper 6 inches is dark gray loamy fine sand grading into yellow fine sandy loam, extending to a depth of 48 inches where it changes to a mottled red, yellow, and white fine sandy clay.

PARTIAL MECHANICAL AND CHEMICAL ANALYSES OF SOILS

Results of the mechanical analysis and the determination of the base exchange capacity, replaceable calcium, and percentage nitrogen for the surface and subsoil samples of these soils are given in Table 1.

The Norfolk sand contained the least fine clay, the Norfolk fine sandy loam the most. The Fellowship fine sandy loam had the highest base exchange capacity and also the most replaceable calcium. Although the Bladen fine sand had a lower base exchange capacity in the surface soil than the Norfolk sand, it had a much higher value for the subsoil.

The mechanical analyses were made by the method of Bouyoucos (3). The base exchange capacity was determined by leaching 50 grams of soil with 1 liter of neutral normal ammonium acetate according to the method of Schollenberger and Dreibelbis (10). Calcium was determined in the filtrate[4] and nitrogen on the original soil samples by the Gunning-Hibbard (1) method.

EXPERIMENTAL PROCEDURE

Glazed coffee urn type pots of 3-gallon capacity were used as small lysimeters. The hole in the bottom of the pot was provided with a rubber stopper through

[4]Unpublished methods of M. Peech.

TABLE 1.—*Some physical and chemical characteristics of soils used in leaching studies.*

Soil	Depth, inches	Fine gravel and sands, 2.0–0.05 mm, %	Silt, 0.05–0.005 mm, %	Clay, <0.005 mm, %	Fine clay, <0.002 mm, %	Nitrogen, %	Milliequivalents per 100 grams of soil: Base exchange capacity	Milliequivalents per 100 grams of soil: Replaceable calcium
Norfolk sand	0–6	96.2	2.3	1.5	0.8	0.035	2.99	0.95
	6–24	95.8	2.7	1.6	1.3	0.011	1.18	0.50
Bladen fine sand	0–8	86.8	7.8	5.4	4.4	0.065	2.47	1.55
	8–30	90.2	4.8	5.0	3.0	0.026	2.68	0.95
Fellowship fine sandy loam	0–8	88.8	7.2	4.0	3.4	0.036	5.12	2.65
	8–20	85.0	7.4	7.7	7.0	0.019	3.85	3.55
Norfolk fine sandy loam	0–6	74.1	17.3	8.6	7.4	0.038	3.91	0.70
	6–10	71.7	14.9	13.4	11.1	0.025	3.29	0.60
	10–20	67.6	13.1	19.3	16.6	0.020	3.43	0.50

which a short piece of glass tubing was inserted for drainage. A cover glass with the convex surface turned upward was used to cover the hole on the inside of the pot and served to prevent loss of sand during leaching.

Sufficient quantities of topsoil and subsoil were air dried in the greenhouse and screened through a 2-mm sieve. The pots were tared with carefully washed white building sand which aided in maintaining the appropriate water content of the cultures.

For comparing the leaching of nitrogen at various intervals after the application of different sources to Norfolk sand, the following procedure was employed: Twenty pounds of the subsoil, equivalent to a depth of 6¼ inches, were placed on top of the building sand in the bottom of the vessel. Distilled water was added to bring the subsoil to the desired moisture content (13%). After a short time, 10 pounds of the topsoil in which the nitrogenous materials had been intimately mixed were added, making a depth of 3 inches of topsoil. Distilled water was then added to bring the topsoil to the desired percentage of moisture (11%). The cultures were allowed to stand until time of leaching with additions of water about once a week to replace that lost through evaporation.

The nitrogenous materials were applied according to the surface area exposed at the rate of 2,000 pounds per acre of a mixture containing 4% nitrogen. This rate amounted to 408 milligrams of nitrogen per culture. Total nitrogen determinations were made on all the fertilizer materials previous to their use. Quantities of the materials equivalent to 408 milligrams of nitrogen were weighed and mixed with the topsoil of each culture, except calcium and ammonium nitrates which were applied in solution because of their deliquescent properties. Ammonium bicarbonate was also added as a solution because of its unstable nature. All cultures were set up in triplicate and kept in a greenhouse where the average temperature was approximately 21°C.

In studying the effect of time of standing or incubation on the amount of nitrogen lost, representative groups of cultures were leached after 1-, 4-, 10-, and

21-day periods with 5 liters of distilled water, equivalent to approximately 4½ inches of rainfall for the surface area. The water was applied in 250-milliliter aliquots to facilitate slow continuous leaching. This quantity of water effected a leaching of 3 to 3½ liters, the equivalent of about 3 inches of water. Three hours were required to leach the 33 cultures of each series.

The chemical analyses were made on the same day that the leachings were collected. The H-ion concentrations were determined on original samples of the leachates by using the glass electrode. Where necessary the leachates were clarified with two drops of a 5% aluminum sulfate solution per 100 milliliters. The different nitrogen compounds were determined colorimetrically by the phenoldisulfonic acid method (11) for nitrates and the dimethylaphanaphthylamine method (11) for nitrites. Ammonia was determined by direct nesslerization with the addition of 1 milliliter of a gum arabic solution for the stabilization of the colloidal precipitate (11). Urea was determined by the difference between the digestion with urease and subsequent distillation and nesslerization of the distillate and the ammonia determination.

In studying the leaching of nitrogen from different soils, after standing for four days, the same procedure was employed as in those involving different periods of incubation. The amounts of topsoil and subsoil used were calculated in proportion to the depths of the profile and the depth of the pots. The amounts of topsoil and subsoils used were as follows: Norfolk sand, 0–6 inches, 10 pounds, 6–24 inches, 20 pounds; Fellowship fine sandy loam, 0–8 inches, 12 pounds, 9–20 inches, 18 pounds; Bladen fine sand, 0–8 inches, 8 pounds, 8–30 inches, 22 pounds; and Norfolk fine sandy loam, 0–6 inches, 9 pounds, 6–10 inches, 6 pounds, 10–20 inches, 15 pounds.

In this second series, nitrogen forms studied were limited to the following sources: Sodium nitrate, ammonium sulfate, urea, and castor pomace. A nitrogen equivalent of 408 milligrams of the materials was mixed with the surface soil and then added to the pot. The topsoil and the subsoil of the cultures were adjusted to predetermined optimum moisture contents with distilled water as outlined above. For obvious reasons the moisture content of the subsoil was adjusted before the surface layers were added.

The cultures of this series were leached after four days with sufficient water to effect a percolate of 3 to 3½ liters, equivalent to approximately 3 inches of water for the surface area. The required amount of water was 5 liters for Norfolk sand, 5½ for Bladen fine sand, 6 for Fellowship fine sandy loam, and 6½ for Norfolk fine sandy loam.

Samples of the surface soil for pH determinations were taken with a cork borer of ⅜ inch diameter just prior to leaching the cultures. Four borings were mixed for each culture. The holes were refilled with dry soil of the same type before leaching. Samples were taken again after leaching in the same manner, avoiding the locations of the previous borings. The determinations were made with the use of a glass electrode after preparing a 1:2 soil-distilled water suspension.

EXPERIMENTAL RESULTS

EFFECT OF TIME OF STANDING OR INCUBATION ON LEACHING OF NITROGEN FROM NORFOLK SAND WHEN APPLIED IN VARIOUS FORMS

The percentage of the total nitrogen applied that was leached from Norfolk sand as nitrates, ammonium ions, and urea after 1, 4, 10,

and 21 days of incubation is given in Table 2. The percentage of nitrogen leached was calculated by subtracting the amount of nitrogen leached from the untreated cultures from the amount leached from the treated cultures and dividing the result by the amount of nitrogen applied.

All nitrate nitrogen was leached after each incubation period whether applied as sodium, calcium, or ammonium nitrate.

Urea was present as such in the leachings from the 24-hour and 4-day incubation periods. Thirty-five per cent of the amount of urea nitrogen applied was present in the leachate from the 24-hour incubation period and 16% from the 4-day period. Tests made on the leachates from the 10- and 21-day periods failed to show the presence of urea. This is probably due to the fact that urea hydrolyzes to ammonium carbonate very quickly in the soil by the action of microorganisms. Therefore, within a few days after application, it should show a reaction similar to that of ammonium carbonate. Very little ammonium nitrogen was leached from the urea cultures until nitrates were formed.

The leachates from the cultures treated with the insoluble organic materials, fish meal, castor pomace, and tankage, contained very little more nitrogen than those from the untreated cultures. A slightly greater quantity of nitrate nitrogen was formed in the treated cultures as shown by the leaching of 0.7 to 3.0% of the nitrogen applied during the 10- and 21-day periods.

The quantities of nitrites leached are shown in Table 3. Nitrite nitrogen did not leach to a great extent. The ammonium carbonate treatment incubated for 10 days gave 4.1 milligrams of nitrite nitrogen per culture. The urea-treated culture gave 1.6 milligrams for the same interval. In most cases there were insufficient quantities to determine. Nitrites have been reported present in some Florida soils in sufficient quantities to cause malnutrition in certain crops (9).

The pH values of the leachates from each incubation period are given in Table 4. The addition of sodium nitrate, calcium nitrate, ammonium nitrate, ammonium phosphate, and ammonium sulfate materially lowered the reaction of the leachates. Ammonium carbonate and urea lowered the pH of the leachate to a lesser extent. The insoluble organic materials had but very slight influence on the pH of the leachate and of these materials fish meal produced the lowest pH values.

COMPARATIVE LEACHINGS OF NITROGEN APPLIED IN VARIOUS FORMS FROM DIFFERENT SOILS AFTER FOUR DAYS OF INCUBATION

To compare the leachability of different nitrogen sources from different soils, four distinct soil types were used and the nitrogen sources were limited to four different forms. On the basis of the results found in the time study reported above, only one incubation period, 4 days, was used.

The percentage of the nitrogen applied which was leached from the different soils is given in Table 5. The pH values of the soils

TABLE 2.—*The percentage of nitrogen leached at different intervals from Norfolk sand following the application of various nitrogen fertilizers.*

	Leached as nitrate				Leached as ammonium				Leached as urea				Total nitrogen leached*			
	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days
Sodium nitrate	105.1	99.0	101.7	96.7	0.4	1.0	1.3	1.3	—	—	—	—	105.5	100.0	103.0	98.0
Calcium nitrate	94.1	91.4	100.4	91.3	3.0	3.8	4.9	4.8	—	—	—	—	97.1	95.2	105.3	96.1
Ammonium nitrate	53.2	52.0	58.0	55.0	17.3	15.4	18.1	18.6	—	—	—	—	70.5	67.4	76.1	73.6
Ammonium phosphate	0.3	2.7	1.2	2.3	10.6	14.0	8.3	2.6	—	—	—	—	10.9	16.7	9.5	4.9
Ammonium carbonate	—	—	3.4	8.8	3.1	—	0.6	6.0	—	—	—	—	3.1	—	4.0	14.8
Ammonium sulfate	—	0.9	2.0	2.0	32.0	41.9	33.1	39.7	—	—	—	—	32.0	42.8	35.1	41.7
Urea	—	—	2.0	8.1	0.1	0.4	1.8	10.6	35.0	16.0	—	—	35.1	16.4	3.8	18.7
Fish meal	—	—	3.3	2.4	0.2	1.7	2.6	9.7	—	—	—	—	0.2	1.7	5.9	12.1
Castor pomace	—	—	2.0	2.2	0.1	0.1	0.9	5.1	—	—	—	—	0.1	0.1	2.9	7.3
Tankage	0.3	—	0.7	1.5	0.1	0.7	0.7	1.8	—	—	—	—	0.4	0.7	1.4	3.3

*Nitrite nitrogen not included in total nitrogen leached.

TABLE 3.—*Milligrams per culture of nitrogen leached as nitrite from Norfolk sand at different intervals following the application of various nitrogen fertilizers.*

Nitrogenous materials added	Period of incubation			
	1 day	4 days	10 days	21 days
Sodium nitrate	0.07	0.02	—	—
Calcium nitrate	0.03	—	—	—
Ammonium nitrate	0.08	—	—	—
Ammonium phosphate	—	—	—	—
Ammonium carbonate	0.08	0.02	4.10	—
Ammonium sulfate	0.03	—	—	—
Urea	0.06	0.02	1.63	0.26
Fish meal	0.03	0.62	0.12	0.27
Castor pomace	0.18	0.60	0.16	0.31
Tankage	0.04	—	—	—
No treatment	0.04	—	—	—

TABLE 4.—*The pH values of leachates from Norfolk sand from cultures treated with various nitrogenous fertilizers after different periods of incubation.*

Nitrogenous materials added*	pH of leachate			
	1 day	4 days	10 days	21 days
Sodium nitrate	6.12	6.02	5.96	5.99
Calcium nitrate	5.38	5.38	5.40	5.20
Ammonium nitrate	5.97	5.89	5.83	5.86
Ammonium phosphate	6.02	5.78	5.97	6.22
Ammonium carbonate	6.50	6.35	6.04	6.14
Ammonium sulfate	6.08	5.76	5.73	5.97
Urea	6.55	6.27	6.24	6.23
Fish meal	6.67	6.21	5.82	6.39
Castor pomace	6.66	6.30	6.50	6.49
Tankage	6.55	6.50	6.52	6.45
No treatment	6.84	6.57	6.85	6.58

*Materials were added at the rate of 408 mgs of nitrogen per culture.

before and after leaching and the pH values of the leachates are given in Table 6.

The nitrogen applied as sodium nitrate was almost completely recovered in the drainage from Norfolk sand (96.7%), Bladen fine sand (96.3%), and Fellowship fine sandy loam (97.6%). The Norfolk fine sandy loam retained a portion of the nitrate nitrogen, 72.2% being leached.

The leaching of nitrogen in the form of the ammonium radical showed great variation with the different soils treated with ammonium sulfate. The ammonium nitrogen leached from the different soils was as follows: Norfolk sand, 40.3%; Bladen fine sand, 3.1%; Fellowship fine sandy loam, 1.8%; Norfolk fine sandy loam, no increase over the untreated culture.

It has been reported that the leaching of ammonium nitrogen varies directly with the base exchange capacity of the soil (7). The data given here bear out this observation, with the exception of Fellowship fine sandy loam which allowed more ammonia to leach than

TABLE 5.—*The percentage of nitrogen leached after four days of incubation from different soils when treated with various nitrogenous materials.*

Treatment	Nitrate, %	Ammonium, %	Total %
Norfolk Sand			
Sodium nitrate	96.7	1.2	97.9
Ammonium sulfate	—	40.3	40.3
Urea	1.5	1.1	2.6
Castor pomace	—	0.1	0.1
Bladen Fine Sand			
Sodium nitrate	96.3	0.5	96.8
Ammonium sulfate	—	3.1	3.1
Urea	—	—	—
Castor pomace	—	—	—
Fellowship Fine Sandy Loam			
Sodium nitrate	97.6	1.0	98.6
Ammonium sulfate	3.1	1.8	4.9
Urea	1.0	—	1.0
Castor pomace	—	—	—
Norfolk Fine Sandy Loam			
Sodium nitrate	72.2	0.7	72.9
Ammonium sulfate	0.5	—	0.5
Urea	0.1	—	0.1
Castor pomace	0.4	—	0.4

Norfolk fine sandy loam. This exception is probably due to the crumb structure of the Fellowship fine sandy loam subsoil. Soils saturated or nearly saturated with calcium ions are very difficult to deflocculate. While the Norfolk fine sandy loam became puddled, exposing the colloidal particles to base exchange, the Fellowship fine sandy loam retained its structure. Consequently, a large percentage of the colloidal particles did not enter into the base exchange activities, at least to the same extent as those with better individual exposure provided by their single particle structure.

No urea was found in the leachates from any of the soils. The average temperature of the greenhouse (29° C) at the time of this study was somewhat higher than that for the earlier series. As a matter of fact, it was very near the optimum reported for urea-hydrolyzing bacteria (13).

The ammonium nitrogen leached from the urea treatments was very small. Norfolk fine sandy loam did not yield sufficient amounts to give a test with Nessler's reagent. The Fellowship fine sandy loam, Bladen fine sand, and Norfolk sand allowed 1% or less of nitrogen to leach in this form.

Castor pomace had no significant effect upon the leaching of either nitrate or ammonium nitrogen for this limited period of incubation.

The acidity of the leachate was greater than that of the soil for all treatments of all soils, both before and after leaching. The pH value of the soil was raised by leaching. This decrease in acidity was not significant in the untreated, urea, and castor pomace cultures. The pH

TABLE 6.—*The pH values of soils and leachates from cultures receiving different sources of nitrogen.**

Nitrogenous material added	pH of soil		pH of leachate
	Before leaching	After leaching	
Norfolk Sand			
Sodium nitrate	5.69	6.31	5.05
Ammonium sulfate	5.46	6.16	4.87
Urea	6.52	6.98	5.16
Castor pomace	6.09	6.36	5.19
No treatment	5.63	5.84	5.16
Bladen Fine Sand			
Sodium nitrate	4.79	5.91	3.97
Ammonium sulfate	4.78	5.69	3.98
Urea	6.10	6.11	4.58
Castor pomace	5.80	5.74	4.48
No treatment	5.42	5.42	4.47
Fellowship Fine Sandy Loam			
Sodium nitrate	5.96	6.40	5.40
Ammonium sulfate	5.80	6.33	5.14
Urea	6.34	6.65	5.59
Castor pomace	6.16	6.44	5.62
No treatment	5.96	6.10	5.53
Norfolk Fine Sandy Loam			
Sodium nitrate	4.87	5.97	4.54
Ammonium sulfate	5.06	5.71	5.61
Urea	6.26	6.06	5.36
Castor pomace	5.72	5.83	5.22
No treatment	5.53	5.61	5.48

*Observations made after an incubation period of four days.

value of the soil was not greatly influenced by the addition of the fertilizer except in the cultures treated with urea where this material appreciably decreased the acidity for the period of the experiment.

SUMMARY

An experiment using small, percolation-type lysimeters was conducted to determine the relative leaching of nitrogen in the form of nitrate, nitrite, urea, and ammonia from Norfolk sand after treatment with several nitrogenous materials, including sodium nitrate, calcium nitrate, ammonium nitrate, ammonium phosphate, ammonium carbonate, ammonium sulfate, urea, fish scrap, castor pomace, and tankage. An equivalent of 408 milligrams of nitrogen was applied to 10 pounds of surface soil and placed in the pot on top of 20 pounds of moistened subsoil. The cultures were established and allowed to stand for 1, 4, 10, and 21 days before being leached with 5 liters of distilled water yielding 3 inches of drainage water for the surface exposed.

The results may be summarized as follows:

1. All nitrogen applied as nitrate was leached.

2. One-third of the ammonium nitrogen applied as ammonium sulfate or ammonium nitrate was leached.

3. The leaching of the ammonium ion from ammonium phosphate was very low.

4. Ammonium carbonate was retained very efficiently by the soil until nitrification began.

5. Urea leached as urea to the extent of 35% and 16% after 1- and 4-day incubation periods, respectively. Ammonium nitrogen was retained very efficiently by the soil until nitrification began. Then, as with ammonium carbonate, both ammonium and nitrate nitrogen leached.

6. Very little difference was noted in the nitrogen content of the leachates from the untreated cultures and the cultures treated with the insoluble organic fertilizers.

A second series of similar cultures using four soil types were treated with sodium nitrate, ammonium sulfate, urea, castor pomace, and no treatment. All cultures were incubated for 4 days before they were leached with sufficient water to effect a quantity of drainage equivalent to 3 inches of water for the surface exposed. The leachates were analyzed for ammonium, urea, and nitrate nitrogen.

The results may be summarized as follows:

1. The nitrates leached almost completely, except from Norfolk fine sandy loam which retained 27.8% in the soil.

2. Forty per cent of the ammonium nitrogen applied as ammonium sulfate leached from Norfolk sand, while insignificant amounts leached from the other soils.

3. No urea was found in any of the leachates.

4. The castor pomace treatment gave very similar results to the no-treatment cultures after 4 days.

5. The leachates showed greater acidity than did the soils.

6. The pH value of the soil was increased by leaching.

7. The most significant effect on the acidity of the soil of any of the materials added was induced by urea which materially raised the pH.

LITERATURE CITED

1. Assoc. Official Agr. Chemists. Official and Tentative Methods of Analysis. Ed. 4. 1935.
2. Bizzell, J. A. Removal of plant nutrients in drainage waters. Jour. Amer. Soc. Agron., 18:130–136. 1926.
3. Bouyoucos, G. J. A comparison of the hydrometer method and the pipette method for making mechanical analysis of soils, with new directions. Jour. Amer. Soc. Agron., 22:747–751. 1930.
4. Collison, S. E. Citrus fertilizer experiments. Fla. Agr. Exp. Sta. Bul. 154: 8–15. 1919.
5. Eckart, C. F. Lysimeter experiments. Hawaiian Sugar Planters' Assoc., Exp. Sta., Div. Agr. and Chem., Bul. 19:1–31. 1906.
6. Moores, C. A., MacIntire, W. H., and Young, B. J. The recovery of soil nitrogen under various conditions as measured by lysimeters of different depths. Tenn. Agr. Exp. Sta. Bul. 138. 1927.
7. Morgan, M. F. Soil changes resulting from nitrogenous fertilization. Conn. Agr. Exp. Sta. Bul. 384. 1936.
8. Parker, F. W. Relation between the equivalent acidity of sources of nitrogen and their efficiency in potato fertilization. Amer. Potato Jour., 3:60–62. 1935.

9. PURVIS, E. R., and RUPRECHT, R. W. Soil and fertilizer studies with celery. Fla. Agr. Exp. Sta. Ann. Rpt. 1937.
10. SCHOLLENBERGER, C. J., and DREIBELBIS, F. R. Analytical methods in base exchange investigations of soils. Soil Science, 30:161–173. 1930.
11. SNELL, F. D., and SNELL, C. T. Colorimetric methods of analysis. New York: D. Van Nostrand and Co. 1936.
12. TIDMORE, J. W., and WILLIAMSON, J. T. Experiments with commercial nitrogenous fertilizers. Ala. Agr. Exp. Sta. Bul. 238. 1932.
13. WAKSMAN, SELMAN A. The Principles of Soil Microbiology. Baltimore: Williams and Wilkins Co. 1927.

THE ANALYSIS OF VARIANCE WITH SPECIAL REFERENCE TO DATA EXPRESSED AS PERCENTAGES[1]

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THERE is considerable diversity of opinion and practice among experimental workers in regard to the validity and use of generalized standard errors, especially with the analysis of variance when applied to complex or pooled experiments. Some workers apply these statistical methods in a mechanical way with little regard to the type of data involved, scant attention being given to any inquiry as to whether the data meet the fundamental assumptions upon which the validity of generalized standard errors depend. On the other hand, certain cautious experimenters sense that their data may not admit combination for the construction of a generalized standard error and, without testing to determine whether their fears are realized, adopt what often is a too conservative policy with respect to pooled estimates of error.

The basic assumption (6)[3] upon which the validity of a generalized standard error depends is that the contributions to experimental error of the several variates constituting the sample, drawn from what might be a distinctly heterogeneous population due to significant-imposed treatments, are in agreement with the sampling theory for a normal population.

COMBINATION OF DISCRETE DATA

There are two principal reasons why experimental data will not or may not justify their combined use to provide a valid estimate of a generalized experimental error. First, the data may be discrete and represent either a Bernoulei (binomial) series or a Lexis series wherein each variate represents a certain number of observations of a given type or condition out of a total number of trials or cases (n). The variance of a single variate of this type is npq. It is clearly dependent on p, the estimated ratio of existence of the type or condition in question, as well as upon n, the total number of trials or cases upon which each variate is based. Bliss (1, 2), Salmon (8), Cochran (4), and others have recognized that each variate in discrete data of this kind does not, therefore, have the same opportunity to contribute equally to a general experimental error. Bliss indicates that R. A. Fisher has supplied a mathematical transformation[4] for such data which will equalize the estimated variance of each variate, leaving it functionally dependent only on n, the total number of trials.

In this transformation each estimate of p is replaced by $Sin^2\Theta$, whence,

$$\Theta = \text{Sin}^{-1}\sqrt{\text{p}} \text{ or } \tfrac{1}{2}\text{ Cos}^{-1}(1-2\text{p}).$$

[1]Contribution from the Agronomy Section, Colorado Agricultural Experiment Station, Fort Collins, Colo. Published with the approval of the Director. Received for publication October 24, 1938.

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[3]Reference by figures in parenthesis is to "Literature Cited", p. 66.

[4]So far as the writers know, Fisher's method of obtaining this transformation has not been published.

Suppose the standard error of an individual variate, np, is estimated by $\sqrt{npq} = n \cdot dp$. Differentiation of the transformation gives $d\Theta = dp/2\sqrt{p(1-p)}$. By substitution, one obtains $d\Theta = \frac{1}{2}\sqrt{n}$ as the estimated standard error of Θ. This expression is clearly seen to be dependent on n only. It is well-known that V(np), the variance of np is npq, or, where the data have been transformed to percentages, $V(p) = pq/n$. It is obvious that the variance changes materially for different values of p, being a maximum when $p = 0.50$, or 50%, and approaching zero as p nears either 0.0 or 1.0. However, $V(\Theta)$, the variance of an individual (Θ), equals $\frac{1}{4}n$ and remains constantly equal to the maximum value of V(p) over the entire range of values of Θ from 0 to $\Pi/2$, where Θ is measured in radians. Fig. 1 illustrates the effect of the transformation on the variance of a single variate.

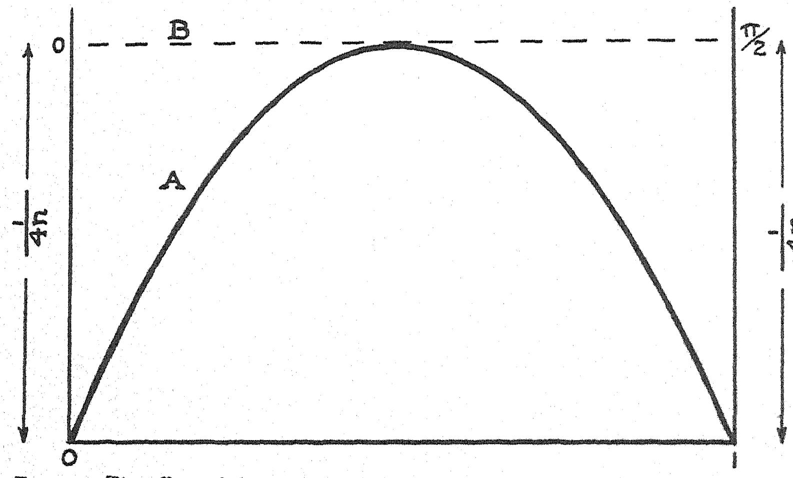

FIG. 1.—The effect of the transformation on a single variate. Curve A indicates how $V(p) = pq/n$ varies as p varies from 0 to 1. Line B shows $V(\Theta) = 1/4n$ as constant as Θ varies from 0 to $\Pi/2$.

DEVELOPMENT OF THE TRANSFORMATION

Let dp represent the standard error of p, i.e., $\sqrt{\frac{pq}{n}}$. Then it is desired to determine a transformation, $p = f(\Theta)$, such that $d\Theta$, representing the standard error of Θ, will be a constant or functionally dependent upon n only. Upon differentiation one obtains $dp = f^1(\Theta)d\Theta$. It is also clear that $dp = \sqrt{\frac{pq}{n}} = \sqrt{\frac{f(\Theta)\,(1-f(\Theta))}{n}}$ and, combining the above expressions, $f^1(\Theta)d\Theta = \sqrt{\frac{f(\Theta)\,(1-f(\Theta))}{n}}$. The requirement that $d\Theta$ be a constant, say $1/C$, is next satisfied so that the above equation becomes

$$\frac{f^1(\Theta)}{\sqrt{\frac{f(\Theta)\,(1-f(\Theta))}{n}}} = C.$$

This differential equation is solved, arbitrarily making $C=2\sqrt{n}$. As a particular solution, one obtains $\mathrm{Cos}^{-1}\,(1-2f(\Theta))=2\Theta$, whence $f(\Theta)=\frac{1-\mathrm{Cos}\;2\Theta}{2}=\mathrm{Sin}^2\,\Theta$. This is the transformation which Fisher sent to Bliss (1, 2). It is evident that the choice of a value for *C* defines the range of the variable (Θ) and consequently its variance.

EMPLOYMENT OF THE TRANSFORMATION

It is clear then that the above transformation must necessarily be applied to discrete data of the type under consideration if it is intended to employ the analysis of variance or any other means that leads to the construction of a generalized standard error. In his original paper (in Russian), Bliss (1) gives a convenient table for the transformation of percentage values to angles, the latter being measured in degrees. However, by use of the form, $\Theta=\frac{1}{2}\,\mathrm{Cos}^{-1}\,(1-2p)$, an ordinary table of trigonometric functions will suffice quite well. When the transformed values of Θ are measured in degrees, it must be remembered that the standard error of Θ will become $\frac{180}{\Pi}\cdot\frac{1}{2\sqrt{n}}$.

It is evident that the variance of Θ is discontinuous under this transformation at the end points of the range, i.e., when p is either 0 or 1. No consideration has been given this circumstance in this paper, although it has been advocated that p values of 0 and 1 be arbitrarily replaced by $\frac{1}{4n}$ and $\frac{4n-1}{4n}$, respectively. However, when a p value of 0 or 1 occurs repeatedly under a given treatment variant under replication, it might be wise to withdraw that portion of the data from the statistical analysis.

It is very important to note that even though the above transformation is applied, it is necessary that *n*, the total number of trials, be kept constant or very close thereto for any generalized standard error to be valid. With data expressed in terms of percentages, an experiment may have all appearance of being completely orthogonal, but when each percentage is based on a different value of *n*, it will really be entirely unorthogonal. Any attempt to employ the analysis of variance must take that fact into account.

TYPES OF PERCENTAGE DATA

In his article on this transformation, Bliss (1) intimates that data expressed as percentages are the source of violation of the basic assumption that underlies the analysis of variance, such data being the type of which the transformation should be applied. This is apt to mislead the experimenter *since the type of discrete data in hand, rather than its expression in terms of percentages, is the criterion for determining a need for the employment of the transformation.* As data expressed in percentages have long troubled experimental workers, it would seem worthwhile to classify types of percentages indicating the nature of each type.

First, continuous data resulting from an experimental study may be expressed as percentages when each variate is divided by an arbitrary constant value, whereby each variate becomes a percentage of some standard or average. Clearly such a procedure merely transforms the unit of measurement. Percentages of this type should be treated statistically exactly as if the data were in their raw form. For example, yield data might be expressed in percentage of the check instead of actual yield in pounds.

Second, continuous data are often expressed in percentages to show concentrations because a comparison of concentrations is the principal objective of the study. This type of percentage is very common. Some examples are: Seed purity given by weight of pure seed/total weight of seed, leafiness given by leaf weight/total plant weight, protein content given by weight of protein/total weight, sugar content given by weight of sugar/weight of root. Such concentrations should not, as a rule, be subjected to any transformation to equalize the variance. However, the technic of each problem that affords percentage data must be considered carefully in deciding whether or not a transformation should be employed to remove a given type of heterogeneity. For instance, percentages of vegetative cover within quadrats estimated at successive time intervals are likely to be heterogeneous when combined. This circumstance would arise because a change in percentage is directly dependent on both the amount of a type of vegetation within the quadrat and also upon its competition with other types. This functional dependence can be expressed by the differential equation $\frac{dp}{dt} = cp\ (1-p)$ which, when solved, affords the transformation $t = \log \frac{1}{1-p}$.

There is a third type of percentage, where the original data are discrete, being based upon a determinate number of trials or cases (n). It is to this type of percentage data that the transformation, $p = \text{Sin}^2\, \Theta$, should be applied to construct an estimate of a generalized standard error. Illustrations of this kind of percentage data are as follows: Germination percentages given by number of seeds germinated/total seeds, disease percentages given by number of plants diseased/total plants, etc.

HETEROGENEITY OF SETS OF ESTIMATED VARIANCES

A second general source of difficulty which frequently prevents a generalized standard error from being a valid estimate is the fact that the different variants of a recognized source of variation incorporated into the experimental design may produce important interaction effects with the unrecognized and uncontrolled sources of variation actually affording the experimental error. Such a situation results in differences of such magnitude in the contributions of the data under the several variants of a given source of variation as are inconsistent with what could be expected on the basis of sampling. It has been recognized that experimental data from different localities or from

different years may often lack sufficient basic homogeneity to admit pooling to form a generalized standard error. However, it is important to realize that different imposed treatment variants may also alter the basic homogeneity of the data to such an extent that the experimental error provided by the analysis of variance may be entirely invalid for any practical use.

Therefore, it is often necessary to subject to scrutiny the basic homogeneity of experimental data to which it is desired to apply the analysis of variance. Stevens (10) has given a method to test the homogeneity of a set of variances which should be applied in case the data should at all suggest heterogeneity among the several variants of any source of variation. This test, devoid of its mathematical development, is next reproduced.

Let V_r, with $r=1, 2—, k$, represent the contributory variances of the k-variants of a source of variation to the construction of a generalized standard error, V, where $V = \frac{S(n_r-1)V_r}{S(n_r-1)}$.

In this case, n_r represents the number of replications within the rth variant, the summations being extended over all the k-variants. Then the expression $\frac{S(n_r-1D(V_r-V)^2}{2V^2}$ is distributed approximately as X^2 with k-1 degrees of freedom (8). Since this modified X^2 is sensitive to differences between variances, it is valuable for testing the hypothesis that each of a set of variances estimates a single variance formed when they are pooled and averaged.

In the mathematical development of this test, it was assumed that each sub-population was normally distributed. Consequently, n_r-1 in the expression for X^2 represents the corresponding degrees of freedom, i.e., the number of variates diminished by one. Some modification is necessary in order to make a more extensive use of the test, as in a complex experiment. The principle of employing the number of degrees of freedom as a multiplying factor must still be maintained. Suppose that variances to other sources of variation in an orthogonal design are to be removed from each of the variances the aggregate of which are being tested for homogeneity. It is necessary to diminish n_r-1 by the corresponding degrees of freedom associated with each of the variances so removed. Some data published by Salmon (8) may be used as an illustration. Ten wheat varieties were each tested with 20 different collections of bunt in two replications. In this case, the number of variates under each of the several varieties would be $n_r=40$. Instead of using $n_r-1=39$, it is necessary to diminish the degrees of freedom that correspond to bunt collections because the variance due to this source was removed in each instance. Therefore, in this problem the multiplying factor employed to form the modified X^2 is $39-19=20$, instead of strictly n_r-1. If the variance due to soil blocks were removed also, it would be necessary to withdraw one more degree of freedom, and thus leave 19.

It should be mentioned that a simpler but inconclusive test will often obviate the need of the homogeneity test outlined above. The investigator can simply divide the largest V by the smallest V in the

set of variances under consideration to form F (9). If this value of F is not significant, the homogeneity of the set of variances may be assumed. Although this test is sufficient to prove homogeneity, it is not at all a necessary condition. When F is significant the X^2 criterion should be employed. It might also be stated that the homogeneity test outlined here and due to Stevens (10) is identical in principle to that devised by Brandt and given by Snedecor (9). Also it should be added that Wishart (11) regards the homogeneity test developed by Bartlett to be superior to and more sensitive than that presented here, particularly if the number of degrees of freedom associated with each variance is small.

ILLUSTRATIVE EXAMPLE FOR HOMOGENEITY TEST

As an adequate illustration of the objectives of this article, it is proposed to analyze that portion of the original percentage data that Salmon (8) saw fit to publish. Table 1 gives these data showing percentages of infection in 10 different wheat varieties with 20 bunt collections at Kearneysville, West Virginia, in 1935. This material is admirably suited as an illustrative example because (a) the percentages were derived from discrete data on infection counts with 200 trials as the value of n in each case; and (b) there is a lack of basic homogeneity in the data under the several variants of at least one of the principal sources of variation, which fact prevents at least that all of the data be combined for the construction of one estimate of experimental error. However, it will be shown that the data are not nearly so incompatible as Salmon (8) indicates, but that a large proportion of them can be pooled to provide a perfectly valid estimate of error.

In the first place, the percentages given in Table 1 are exactly the type that necessitate the employment of the transformation, $p = \text{Sin}^2\,\Theta$. The transformed data are presented in Table 2.[5]

In order to investigate whether these transformed data may be subjected to an analysis of variance, the estimate of variance within each variety is first computed to measure the variation of each pair of replicates about the mean of each pair. The number of degrees of freedom will be $39-19=20$, since only variance between bunt collections is removed. Table 3 presents the variances for the different varieties of wheat, which are subsequently subjected to the homogeneity test, together with the standard errors for the varieties.

The computation for the homogeneity test is as follows:

$X^2 = \dfrac{S(n_r-1)\,(V_r-V)^2}{2V^2} = \dfrac{20\times 909.5185}{(2\times 23.9586)^2} = 15.844$. This is treated as X^2 with nine degrees of freedom. A table of probabilities for X^2 values indicates that the probability of obtaining, as a result of sampling, a value as large or larger than 15.844 to be approximately 0.104. The result is not significant, but it suggests possible danger in the con-

[5]To illustrate the use of a table of cosines for the transformation of a percentage to an angle, consider $p=86.6\%=0.866$ for collection 1 and replication 1 for Hybrid 128. Then as $\Theta = \frac{1}{2}\,\text{Cos}^{-1}\,(1-2p)$, one obtains $\Theta = \frac{1}{2}\,\text{Cos}^{-1}\,(1-1.732) = \frac{1}{2}\,\text{Cos}^{-1}\,(-0.732)$. A table of cosines gives $\text{Cos}^{-1}\,(-0.732) = 137.06°$. Then, $\Theta = \frac{1}{2}\,(137.06°) = 68.53°$.

TABLE 1.—*Percentage infection in different varieties of wheat with 20 collections of bunt at Kearneysville, West Virginia, in 1935.*

Bunt collection No.	Hybrid 128		Turkey		Minturki		Oro		Ridit		Albit		Martin		Hohen-heimer		White Odessa		Hussar		Av. % bunt
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
1	86.6	80.7	8.3	6.5	79.1	72.8	0.0	0.9	6.3	3.9	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.5	0.6	17.5
2	76.4	95.2	89.0	84.3	90.6	84.3	2.5	3.6	8.7	2.2	92.4	90.6	18.4	16.0	0.0	1.4	97.5	98.1	81.0	74.9	55.4
3	94.9	93.3	3.3	6.0	87.9	75.4	1.5	0.0	6.0	0.7	93.7	90.1	84.5	64.8	0.0	0.0	97.8	94.4	0.0	0.7	44.8
4	91.0	91.7	81.7	87.2	92.0	82.6	1.5	6.3	4.1	3.1	14.0	4.5	0.0	3.0	0.0	0.0	75.9	84.7	0.0	0.7	36.3
5	83.7	90.2	7.5	2.4	60.6	80.9	0.6	1.6	3.9	3.6	4.2	3.2	0.0	2.2	2.4	2.5	0.7	0.0	0.0	0.7	17.7
6	88.9	92.2	5.6	7.4	52.5	39.4	1.1	0.0	2.2	0.0	0.0	0.0	5.0	0.6	0.0	0.0	0.0	0.0	1.6	0.0	14.9
7	97.5	97.9	13.7	9.0	55.6	44.3	0.0	0.8	2.0	1.8	0.0	0.9	1.4	0.8	7.1	0.0	2.0	1.9	0.0	0.0	16.9
7a	81.5	92.2	17.4	9.8	85.4	83.3	1.2	4.4	5.2	4.9	85.2	82.5	61.1	62.0	0.9	5.6	68.8	86.5	1.1	0.0	43.0
8	92.8	91.5	8.5	8.4	30.3	30.4	1.6	1.1	1.2	0.0	0.0	0.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
9	97.3	92.6	15.4	3.8	17.2	11.7	3.3	0.0	3.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	8.4	0.8	2.5	0.0	12.9
10	93.7	83.3	5.8	1.3	71.2	63.7	3.1	0.0	4.2	3.8	92.1	79.6	77.9	77.0	0.9	0.0	90.4	74.6	1.2	0.8	41.3
11	83.0	77.8	3.8	1.1	70.6	69.9	0.5	1.7	6.8	5.5	2.1	3.9	0.6	0.9	0.0	0.0	1.3	0.0	0.0	0.0	16.6
12	82.1	79.5	9.8	4.7	49.5	75.2	0.0	0.0	15.5	0.0	50.0	76.5	75.5	74.5	0.0	0.0	74.1	79.1	2.8	0.6	37.7
13	80.2	80.7	5.6	10.9	61.9	60.9	0.0	2.0	0.8	10.8	0.6	0.0	2.0	0.0	6.1	12.2	2.1	7.3	1.2	0.0	17.3
14	78.3	77.7	82.5	54.7	76.4	79.7	3.5	7.5	12.7	12.5	81.9	87.2	75.5	76.4	1.1	1.3	88.8	91.2	62.6	69.7	56.1
15	80.0	95.5	10.3	7.3	79.7	83.8	2.4	1.1	10.1	2.2	78.8	90.6	70.1	69.2	0.0	0.0	85.8	98.0	2.1	0.0	43.4
32	85.8	97.8	76.5	92.6	90.9	80.9	59.8	75.0	14.4	5.2	0.0	0.0	2.3	2.1	0.0	0.0	0.0	0.0	1.0	3.3	34.4
51	94.2	95.5	28.3	21.5	45.1	40.0	0.6	1.2	4.8	4.7	0.8	2.6	0.0	0.0	0.0	0.0	5.1	1.4	0.5	0.0	17.4
157	75.0	86.3	52.4	92.1	75.3	85.3	2.2	0.9	1.4	1.0	89.2	85.0	47.0	82.2	0.0	0.0	83.4	90.5	45.5	37.6	51.6
189	87.3	94.6	79.5	92.0	81.1	80.2	7.5	4.7	4.9	6.1	91.9	94.6	71.0	78.0	2.9	1.2	96.4	96.7	53.2	70.2	59.7
Average	87.2	90.7	43.7	46.2	76.9	77.9	3.7	4.4	4.5	4.2	28.5	29.1	23.0	22.5	0.4	0.8	33.3	33.4	10.9	10.6	
Grand av.	89.0		45.0		77.4		4.1		4.4		28.8		22.8		0.6		33.4		10.8		

TABLE 2.—*Percentage data from Table 1 transformed to degrees by the transformation,* $p = \sin^2\theta$.

Bunt collection No.	Hybrid 128		Turkey		Minturki		Oro		Ridit		Albit		Martin		Hohenheimer		White Odessa		Hussar	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	68.53	63.94	16.74	14.77	62.80	58.56	0.00	5.44	14.54	11.39	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	4.05	4.44
2	60.94	77.34	70.63	66.66	72.15	66.66	9.10	10.94	17.16	8.53	74.00	72.15	25.40	23.58	0.00	6.80	80.90	82.08	64.16	59.93
3	76.95	75.00	10.47	14.18	69.64	60.27	7.04	0.00	14.18	4.80	75.46	71.66	66.81	53.61	0.00	0.00	81.47	76.31	0.00	4.80
4	72.54	73.26	64.67	69.04	73.57	65.35	7.04	14.54	11.68	10.14	21.97	12.25	0.00	9.98	0.00	0.00	60.60	66.97	0.00	4.80
5	66.19	71.76	15.89	8.91	51.12	64.08	4.44	7.27	11.39	10.94	11.83	10.31	0.00	8.53	8.91	9.10	4.80	0.00	0.00	4.80
6	70.54	73.78	13.69	15.79	46.43	38.88	6.02	0.00	8.53	0.00	0.00	0.00	12.92	4.44	0.00	0.00	0.00	0.00	7.27	0.00
7	80.90	81.67	21.72	17.46	48.22	41.73	0.00	5.13	8.13	7.71	0.00	5.44	6.80	5.13	15.45	0.00	8.13	7.92	0.00	0.00
7a	64.52	73.78	24.65	18.24	67.54	65.88	6.29	12.11	13.18	12.79	67.37	65.27	51.41	51.94	5.44	13.68	56.04	68.44	6.02	0.00
8	74.44	73.05	16.95	16.85	33.40	33.46	7.27	6.02	6.29	0.00	0.00	4.44	7.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	80.54	74.21	23.11	11.24	24.50	20.00	10.47	0.00	9.08	0.00	0.00	5.13	0.00	0.00	0.00	0.00	16.85	5.13	9.10	0.00
10	75.46	65.88	13.94	6.55	57.54	52.95	10.14	0.00	11.83	11.24	73.57	63.15	61.96	61.34	5.44	0.00	71.95	59.74	6.29	5.13
11	65.65	61.89	11.24	6.02	57.17	56.73	4.05	7.49	15.12	13.56	8.33	11.39	4.44	5.44	0.00	0.00	6.55	0.00	0.00	0.00
12	64.97	63.08	18.24	12.52	44.71	60.13	0.00	0.00	23.19	0.00	45.00	61.00	60.33	59.67	0.00	0.00	59.41	62.80	9.63	4.44
13	63.58	63.94	13.69	19.28	51.88	51.30	0.00	8.13	5.13	19.19	4.44	0.00	8.13	0.00	14.30	20.44	8.33	15.68	6.29	0.00
14	62.24	61.82	65.27	47.70	60.94	63.22	10.78	15.89	20.88	20.70	64.82	69.04	60.33	60.94	6.02	6.55	70.45	72.74	52.30	55.49
15	63.44	77.75	18.72	15.62	63.22	66.27	8.91	6.02	18.53	8.53	62.58	72.15	56.85	56.29	0.00	0.00	67.86	81.87	8.33	0.00
32	67.86	81.47	61.00	74.21	72.44	64.08	50.65	60.00	22.30	13.18	0.00	0.00	8.72	8.33	0.00	0.00	0.00	0.00	5.74	10.47
51	76.06	77.75	32.14	27.63	42.19	39.23	4.44	6.29	12.66	12.52	5.13	9.28	0.00	0.00	0.00	0.00	13.05	6.80	4.05	0.00
157	60.00	68.28	46.38	73.68	60.20	67.45	8.53	5.44	6.80	5.74	70.81	67.21	43.28	65.05	0.00	0.00	65.96	72.05	42.42	37.82
189	69.12	76.56	63.08	73.57	64.23	63.58	15.89	12.52	12.79	14.30	73.46	76.56	57.42	62.03	9.81	6.29	75.56	79.53	46.83	56.91
Mean*	69.224	71.811	31.111	30.499	56.200	54.991	8.553	9.167	13.215	9.268	32.939	33.822	27.020	26.815	3.269	3.134	37.446	37.903	13.624	12.452
Grand mean	70.517		30.805		55.595		8.859		11.241		33.380		26.918		3.201		37.674		13.038	

*Mean values of θ by varieties.

TABLE 3.—*Variances for varieties (transformed data).*

Variety	V_r	$s_r=\sqrt{V_r}$	$(V_r-V)^2$
Hybrid 128	27.2695	5.22	10.9621
Turkey	45.3931	6.74	459.4278
Minturki	22.4772	4.74	2.1945
Oro	17.1502	4.14	46.3543
Ridit	32.7946	5.73	78.0749
Albit	18.4381	4.29	30.4759
Martin	27.7772	5.27	13.5817
Hohenheimer	10.8210	3.29	172.5965
White Odessa	23.1647	4.81	0.6303
Hussar	14.2005	3.77	95.2205

$$V=\frac{S(V_r)}{10}=23.9586 \qquad S(V_r-V)^2=909.5185$$

solidation of the data. It indicates that the variances within the several collections of bunt should be subjected to a like test. Table 4 presents the pertinent statistics for the 20 bunt collections.

TABLE 4.—*Variances for bunt collections (transformed data).*

Bunt collection No.	V_r	$s_r=\sqrt{V_r}$	$(V_r-V)^2$
1	7.5992	2.75	267.6300
2	23.2495	4.82	0.5028
3	24.0525	4.90	0.0088
4	20.1750	4.49	14.2156
5	18.8544	4.34	26.0529
6	15.2837	3.91	75.2539
7	17.9242	4.23	36.4140
7a	21.3102	4.62	7.0140
8	5.7819	2.40	331.3924
9	32.8461	5.73	67.8999
10	27.9804	5.29	16.1749
11	5.4522	2.34	342.4868
12	55.3353	7.44	984.4973
13	25.6154	5.06	2.7450
14	18.7053	4.32	27.5972
15	34.4620	5.87	110.3214
32	31.1374	5.58	51.5353
51	5.6394	2.38	335.5931
157	71.1112	8.43	2223.3677
189	16.6565	4.08	53.3207

$$V=\frac{S(V_r)}{20}=23.9586 \qquad S(V_r-V)^2=4974.0227$$

The homogeneity test gives $\dfrac{S(n_r-1)\ (V_r-V)^2}{2V^2}=\dfrac{10\times 4974.0227}{2(19.5959)^2}=$ 64.765. A table of probabilities shows that the probability of obtaining a value of 36.191 for 19 degrees of freedom to be 0.01. Hence, the obtained value, 64.765, must be interpreted as extremely significant. It clearly indicates that the variances within the several bunt collections cannot be estimates of the same value. As a result, it can only be concluded that the data considered cannot be combined in their entirety in an analysis of variance.

However, a critical examination of the data indicates that the construction of a useful generalized standard error may still be possible. It seems that the extreme lack of homogeneity exhibited by the variances within bunt collections is principally due to but two collections, i.e., Nos. 12 and 157. When the data afforded by these two collections are neglected altogether, the remainder of the data being re-subjected to the homogeneity test, it is found that the variances within varieties provide a modified $X^2=7.692$, which interpreted on the basis of nine degrees of freedom has a probability 0.57 of occurrence. The homogeneity test applied to the variances within the 18 remaining bunt collections shows a modified $X^2=18.669$ which, interpreted for 17 degrees of freedom, has an approximate probability 0.36 of occurrence.

It is now evident that the vast majority of the original data can be treated by the analysis of variance, the results of which are given in Table 5.

TABLE 5.—*Complete analysis of variance (transformed data).*

Variation due to	Sums of squares	Degrees of freedom	Mean square	Standard error	F
Blocks	33.72	1	33.72	——	2.00
Varieties	149,809.43	9	16,645.49	——	988.45*
Collections	55,833.74	17	3,284.34	——	195.03*
Varieties × collections	91,781.71	153	599.88	——	35.62*
Varieties × blocks	229.51	9	25.50	——	1.51
Collections × blocks	689.05	17	40.53	——	2.41*
Error	2,576.38	153	16.84	4.1037	——
Total	300,953.54	359			

*Exceeds the 1% point.

The standard errors for varieties, bunt collections, and varieties × bunt collections, are as follows:

$$s_v = \frac{4.1037}{\sqrt{36}} = 0.68$$

$$s_b = \frac{4.1037}{\sqrt{20}} = 0.92$$

$$s_{bv} = \frac{4.1037}{\sqrt{2}} = 2.90$$

SAMPLING THEORY INVOLVED

In this experiment where $n=200$, the total heads observed from each row, the theoretical variance of an individual observation transformed from p to Θ, would be $V=\frac{1}{4n}=\frac{1}{800}$ for Θ measured in radians. Since Θ is given in degrees here, the standard error must be multiplied by $180/\Pi$ so that $V=\frac{1}{4n}\left(\frac{180}{\Pi}\right)^2=4.1035$.

There is a serious discrepancy between this value and 16.84, the mean residual or error variance actually afforded by the data. Salmon (8) noted a comparable discrepancy in treating the raw percentage data but rather unfairly intimates that the binomial distribution strictly applies only to coin-tossing problems or like schemata. Without doubt, the principal explanation that sampling theory based on a simple binomial distribution fails to account for the large experimental variance obtained is because the population sampled is not distributed in an ordinary binomial distribution due to the fact that the head rather than the plant is taken as the unit of observation. The correlation between infection and heads from the same plant will be extremely high. To illustrate the effect of this correlation in increasing the variance, consider a sample of 200 heads taken from 50 plants, 4 heads from each plant. For an assumed perfect correlation, the theoretical variance of an obtained percentage of infection would be $\frac{4pq}{n}$ instead of $\frac{pq}{n}$ as expected from sampling one head from each of 200 plants (4, 6).

Therefore, the method of sampling by observing heads can be held accountable for the fact that the obtained variances are much greater than the theoretical variance expected from simple sampling. They also account for the lack of uniformity of the number of heads to the number of plants sampled. Very clearly this practice might produce a type of heterogeneity in the data which precludes it in the aggregate from providing a single valid standard error of estimate. Also, the fact that certain check varieties may be included which are extremely susceptible to infection may produce a distinct heterogeneity due to an abnormal variety population.[6]

CONCLUSIONS

1. Discrete data representing counts of a given type, condition, or attribute and based on a determinate number of trials should be subjected to the transformation $p = \mathrm{Sin}^2\,\Theta$ where it is proposed to combine them in any way to construct a generalized standard error. Whether such data represent the actual counts or percentages derived from them does not alter the situation.

2. The above transformation was suggested by R. A. Fisher. Its mathematical development based upon the need for equalizing variances is here presented.

3. Percentage data in general are classified into three types in order to indicate more clearly when and when not to employ this transformation.

4. The need is emphasized for subjecting data under imposed sources of variation to a homogeneity test when it is proposed to treat the combined data by an analysis of variance.

[6]Correspondence with Dr. S. C. Salmon indicates that the data at hand resulted from sampling not more than two heads per plant. In view of this fact, a lesser emphasis than is indicated in the body of this paper should be placed upon sampling technic as the reason for a high experimental variance. Likewise, Salmon's explanation of variable experimental conditions, including soil moisture and temperature as affecting variances, assumes an added significance.

5. Some of the reasons are presented for the heterogeneity of variances which sometimes results under the several variants of an imposed source of variation. In particular it is suggested that this undesirable type of heterogeneity appearing in smut data is attributable to lack of uniformity in sampling due to the choice of the head rather than the plant as the sampling unit.

6. It is also indicated through illustration that even though data in their entirety exhibit such heterogeneity as to make an analysis of variance invalid, it may be possible to eliminate the data under certain variants of a source of variation and still combine the majority of the data for the determination of a valid generalized standard error with but little loss of information and generality.

LITERATURE CITED

1. BLISS, C. I. The analysis of field experimental data expressed in percentages. Leningrad: Plant Protection Bul. 12, U.S.S.R. 1937.
2. ————. The transformation of percentages for use in the analysis of variance. Ohio Jour. Sci., 38:No. 1, 1938.
3. BARTLETT, M. S. Properties of sufficiency in statistical tests. Proc. Roy. Soc., A, 160:268–282. 1937.
4. COCHRAN, W. G. Some difficulties in the statistical analysis of replicated experiments. Emp. Jour. Agr., 6:157–175. 1938.
5. FISHER, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 5. 1934. (Pages 70 and 102.)
6. IRWIN, J. O. Mathematical theorems involved in the analysis of variance. Jour. Roy. Stat. Soc., 94, Part II. 1931.
7. POWERS, L., and CLARK, A. Failure of chromosome pairing as evidence of secondary diploidy in *Zea mays*. Jour. Gen., 35:301–313. 1937.
8. SALMON, S. C. Generalized standard errors for evaluating bunt experiments with wheat. Jour. Amer. Soc. Agron., 30:647–663. 1938.
9. SNEDECOR, G. W. Statistical Methods. Ames, Iowa: Collegiate Press. 1937. (Page 196.)
10. STEVENS, W. L. Heterogeneity of a set of variances. Jour. Gen., 33:398–399. 1936.
11. WISHART, J. Field experiments of factorial design. Jour. Agr. Sci., 28:299–306. 1938.

THE RESPONSE OF QUACK GRASS TO VARIATIONS IN HEIGHT OF CUTTING AND RATES OF APPLICATION OF NITROGEN[1]

A. A. JOHNSON AND S. T. DEXTER[2]

QUACK grass, *Agropyron repens* (*L*) Beauv., occupies large land acreages in Michigan and other northern states and has become a plant of considerable importance. The plant has a tenacious rhizomatic habit of growth and is difficult to eradicate. Several methods of quack grass control are practiced nearly all of which involve the exhaustion of root reserves and removal of photosynthetic tissue.

The following paper reports a study of defoliation of quack grass cultures, some high and some low in nitrogen. These were defoliated at various heights for a considerable period of time and the various effects on roots and rhizomes and new top growth were observed.

REVIEW OF LITERATURE

A study of the literature (2, 3, 4, 5)[3] reveals that root and rhizome development and yield of grasses are influenced by the cutting treatment. In general, the more frequent and complete the defoliation the less is the yield of roots, rhizomes, and tops. Severe defoliation and application of nitrogen to grasses having abundant reserves stimulates a vegetative response, the carbohydrate reserves are rapidly consumed, and with slight opportunity for replenishment they often become the principal factors limiting growth.

As pointed out by Dexter (1) it is difficult to exhaust the organic reserves of quack grass or to place it in a condition where it is susceptible to injury by defoliation.

METHODS AND MATERIALS

On July 12, 1937, ten quack grass rhizome segments, 2 to 3 inches long, were placed in each of 80 10-inch clay pots. The plants were grown in the greenhouse at East Lansing, Michigan. Sand cultures were used throughout the experiment. The plants were supplied with a three-salt nutrient solution designated as type IR_2S_4.[4] The nutrient solution was applied by the slop culture technic.

Growth of the plants was steady and at the end of two months the pots were well filled with vigorous plants showing good rhizome development. On September 20, the nutrients were flushed out of 40 of the pots by repeated applications of tap water, the water being allowed to drip through the pot before each succeeding application. From this date to the conclusion of the experiment these plants were grown in a nutrient solution containing no nitrogen. This was accomplished by substituting calcium chloride for calcium nitrate in equal molar quantities.

[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article 338 (N.S.). Received for publication November 7, 1938.

[2]Assistant in Crops and Research Associate, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 76.

[4]LIVINGSTON, B. E. A plan for cooperative research on the salt requirements of agricultural plants. Ed. 2. 1919.

The other 40 cultures were supplied continuously with available nitrogen. For convenience, these cultures will be known as minus and plus nitrogen cultures, respectively.

On October 29, 1937, three plus and three minus nitrogen cultures were washed free of sand. Green and dry weight determinations were made on the roots, rhizomes, and tops. These cultures served as initial checks. On the same date 30 plus and 30 minus nitrogen cultures were divided each into five groups of six cultures each. For each of the five groups, both plus and minus nitrogen, a different cutting practice was followed. On October 29, and at weekly intervals thereafter the cultures were cut as follows: Group 1 was defoliated as close to the sand level as possible; group 2 was cut back to 1 inch above the sand level; group 3 to 3 inches; group 4 to 6 inches; and group 5 to 8 inches above the sand level. Green and dry weight determinations of recovery growth above these levels were made on each individual culture for each clipping date. In cases where this "recovery" growth was very small, the clippings from the six replications of a given group were weighed as one. After cutting from September to February 1, two cultures from the close cutting treatments, both plus and minus nitrogen, were covered to shut out all light and prevent photosynthetic activity.

On April 5, when the experiment was concluded, the sand was carefully washed from the roots and rhizomes of all the cultures which were alive. The rhizomes, roots, and tops were separated and the green and oven-dry weight for each determined. At the close of the experiment three plus and three minus nitrogen cultures which had not been cut throughout the experiment were washed out and weighed likewise and served as final checks.

The root and rhizome systems of representative cultures of the various cutting treatments both plus and minus nitrogen were examined at frequent intervals. This examination was accomplished by lifting the cultures out of the pot by the leaves or by tipping the pots. This method left the sand intact around the roots and rhizomes and facilitated replacement of the culture without undue disturbance.

On April 5, photographs were taken of a representative culture from each cutting treatment, both plus and minus nitrogen and both before and after cultures were washed out.

DATA

When the cutting treatments were initiated on October 29, the plus nitrogen plants had a vigorous top, rhizome, and root growth. The leaves were dark green in color and tended to droop over the edges of the pot. The minus nitrogen plants were very similar to the plus nitrogen plants in rhizome and root development but had less top growth. In contrast with the leaves on the plus nitrogen plants, those of the minus nitrogen plants were lighter green in color, stiff and upright. This contrast in leaf character between the plus and minus nitrogen plants became more and more pronounced as the experiment progressed. This was particularly true of those not cut at all. This difference is shown in Figs. 1 and 2.

The average production of dry weights of clippings for all cutting treatments is shown in Table 1. The data show that through the first and second four-week periods of cutting the plus nitrogen close-cutting cultures made more recovery growth each week than any other cutting treatment. After the second four-week period, the plus

nitrogen 6-inch cutting made on the average the most recovery growth. The 1- and 3-inch cutting treatments produced more recovery growth than did close cutting after the fourth four-week period.

In the plus nitrogen cultures the greatest total dry weight of clippings removed was made by the 6-inch cutting. It was, however, only slightly greater than that made by the plus nitrogen close cut-

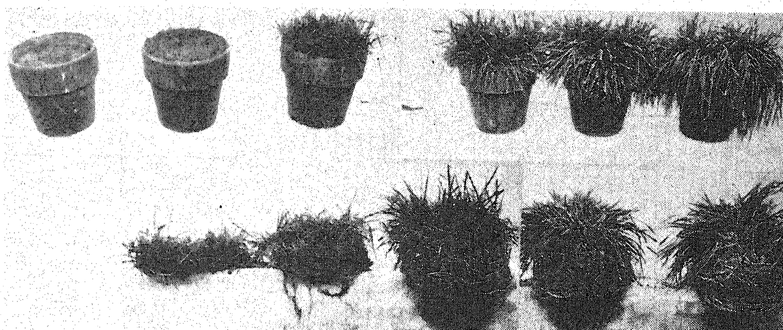

FIG. 1.—Plus nitrogen quack grass cultures. This photograph was taken April 5, one week after cutting. From left to right a representative culture from each cutting treatment is shown as follows: Completely defoliated; cut to 1, 3, 6, and 8 inches once a week for 24 weeks; and uncut or check.

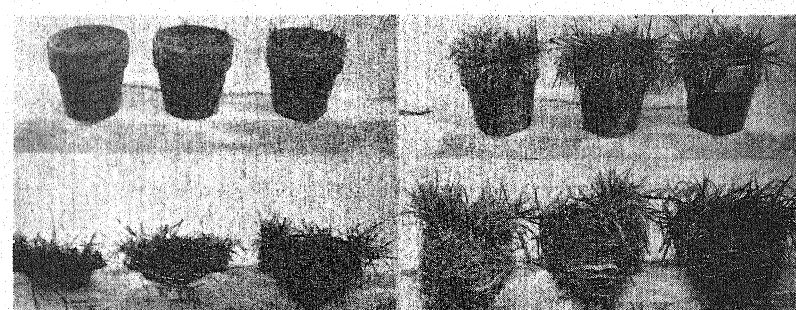

FIG. 2.—Minus nitrogen quack grass cultures. This photograph was taken April 5, one week after cutting. From left to right a representative culture from each cutting treatment is shown as follows: Completely defoliated; cut to 1, 3, 6, and 8 inches once a week for 24 weeks; and uncut or check.

ting treatment. After removal of the original top growth the minus nitrogen close-cut cultures produced in the 23 weekly cuttings almost as much recovery growth as the plus nitrogen close-cutting treatment and about twice as much dry matter as any other cutting treatment in the minus nitrogen series.

Through the twelfth week the recovery growth of the plus nitrogen close cutting treatment measured from 3 to 6 inches in height each week. Up to the last few weeks the recovery growth of all other cultures receiving nitrogen was shorter than that of the cultures cut

close. In general, the recovery growth of the minus nitrogen close cutting was about an inch shorter than that of the plus nitrogen close cutting treatment, even though the dry weights were about the same.

TABLE 1.—*Dry weights in grams by four-week periods of clippings removed at weekly intervals from plus and minus nitrogen cultures.*

Weekly treatment	1st 4 weeks	2nd 4 weeks	3rd 4 weeks	4th 4 weeks	5th 4 weeks	6th 4 weeks	Total recovery growth
			Plus Nitrogen Cultures				
Complete removal of top growth (close cutting)..	6.77	2.73	2.00	1.29	0.69	0.17	13.43
Cut back to 1 inch........	4.11	1.55	1.76	1.28	1.77	1.32*	10.46
Cut back to 3 inches......	4.18	2.03	1.34	1.03	1.15	2.33*	11.50
Cut back to 6 inches......	2.64	1.33	2.91	1.67	2.68	4.01*	14.24
Cut back to 8 inches......	1.58	0.34	0.95	0.23	1.01	1.13*	5.24
			Minus Nitrogen Cultures				
Complete removal of top growth (close cutting)..	5.21	2.36	1.28	1.01	1.31	1.15*	12.03
Cut back to 1 inch........	1.82	0.85	1.02	0.69	1.04	0.89*	6.09
Cut back to 3 inches......	2.38	0.69	0.88	0.72	0.73	0.61*	5.84
Cut back to 6 inches......	1.38	0.03	0.32	0.16	—	0.31*	1.89
Cut back to 8 inches......	1.14	0.04	—	—	—	—	1.18

*Four-thirds of last 3 weeks' growth.

As the experiment progressed, the leaves produced by the plus nitrogen close cutting treatment became narrower and paler in color. This tendency was also apparent in the minus nitrogen close cutting treatment but was at no time so pronounced. The leaf color of the other plus nitrogen plants tended to vary somewhat with the amount of sunlight. During a prolonged period of very low sunlight the plants became a paler green and as the sunlight increased, the deep green color returned. The minus nitrogen plants stayed a pale green color throughout the experiment.

Only two cultures of the plus nitrogen close-cutting treatment had any green shoots on April 5. Of these two, one was covered on February 1 so as to prevent photosynthetic activity and the other was left uncovered throughout the experiment. In these, only two or three weak shoots per pot were visible. In this cutting treatment three cultures failed to produce new shoots on and after March 15, and one culture failed to produce new shoots on and after March 29. Since one of the cultures which was covered on February 1 was still producing shoots on March 29, it is seen that covering these cultures had no apparent effect in hastening the death of the plants. No difference in rhizome or root development could be noted in the minus nitrogen cultures which were covered on February 1 as compared to those left uncovered and all were still alive.

The various cutting treatments had a marked effect on the subterranean parts of the plus nitrogen plants in particular. These effects were first noticed in the close cutting treatment. Within two

weeks after cutting was started some of the rhizomes had started to die back from the tips. By the end of the sixth week many of the rhizomes had died back to the second or third node, the tips taking on a water-soaked appearance. In the plus nitrogen 1-inch cutting cultures, the rhizome tips had started to die back by the fifth week of cutting but in the 3-inch cutting this took place much later and only to a limited extent. About the fifth week of cutting, the rhizome tips started to die back in the minus nitrogen close cutting treatment, while in the 1-inch cutting this dying back was apparent somewhat later and only to a limited extent. No dying back was apparent in the minus nitrogen 3-inch cutting at any time during the course of the experiment.

In the close and 1-inch cutting groups of the plus nitrogen cultures a number of rhizome tips turned upward and produced green leaves upon emergence. Likewise, some of the lateral buds initiated shoots which, upon emergence, produced green leaves. There was a limited increase in the number of new culms during the first few weeks, but the number decreased steadily thereafter, especially in the close-cutting treatment. After a few weeks of cutting the shoots produced in the plus nitrogen close-cutting treatment were found entirely around the outer rim of sand in the pot. To a lesser extent this was also true in the cultures receiving nitrogen and cut to 1 or 3 inches. Plus nitrogen cultures cut at 6 and 8 inches thickened up throughout.

In the minus nitrogen cultures cut close, about one-half of the rhizome tips turned upward and only a few of the lateral buds initiated shoots. After a few cuttings the new shoots of the minus nitrogen close-cutting treatment were found mostly around the outer rim of sand in the pot. The rhizome weights in grams are presented in Table 2. Figs. 1 and 2 show the appearance and comparative abundance of rhizomes, roots, and tops of typical cultures from the various cutting treatments.

Where nitrogen was supplied and the plants were cut close once a week for 24 weeks, the rhizome weight was negligible. Only one piece of rhizome about 3 or 4 inches long was left in each of two of these cultures. Cultures receiving nitrogen cut to 1 inch lost in total rhizome weight when compared to the initial checks. In the culture cut to 3 inches there was a small loss in rhizome weight. The rhizome weight of the quack grass under the minus nitrogen close-cutting treatment about equaled that of the plus nitrogen 1-inch cutting, while the rhizome weight of the minus nitrogen 1-inch cutting approximated that of the plus nitrogen 3-inch cutting treatment.

Fig. 3 is a photograph (taken April 5) of frayed discolored rhizomes from a plus nitrogen close-cutting culture and healthy rhizomes from a plus nitrogen check culture.

By January 11, or after 12 weeks of cutting, the root systems of the plus nitrogen close-cutting series had started to disintegrate. Disintegration of the root system was virtually complete by the end of the fifteenth week of cutting. When the experiment was discontinued after 24 weekly clippings, the root systems of the plus nitrogen 1-inch cultures also were disintegrated completely and the roots of

FIG. 3.—Healthy rhizomes from plus nitrogen check culture at left and dead rhizomes from plus nitrogen close-cut culture at right.

the cultures receiving nitrogen and cut at 3 inches were showing some decay.

In all the cutting treatments of the minus nitrogen plants the roots were abundant at the close of the experiment. The root weights of the close, 1- and 3-inch cutting treatments were less than that of the initial checks, but all of the roots were of good color and had every appearance of being functional. (See Fig. 2.)

Data in Table 2 show that the average total plant weight in both the plus and minus nitrogen treatments in the close, 1-, and 3-inch cutting groups was less than that of the initial check. There was very little difference in the average total plant weight of the 6- and 8-inch cutting groups and final

TABLE 2.—*Dry weight in grams of rhizomes, roots, and tops from plants grown with and without nitrogen after 24 consecutive weeks of cutting. Weights from initial and final uncut checks are included.*

Treatment	Rhizomes	roots	Tops	Total
Plus Nitrogen Plants				
Complete removal of top growth (close cutting)	0.02	0.0	0.02	0.04
Cut back to 1 inch	12.8	0.8	6.8	20.4
Cut back to 3 inches	27.3	6.9	15.8	50.0
Cut back to 6 inches	52.3	18.1	33.1	103.4
Cut back to 8 inches	64.7	23.2	63.0	150.9
Initial check (plants harvested before cutting was begun)	34.4	27.8	36.7	98.9
Final check (plants left uncut and harvested at end of experiment	76.6	27.8	60.7	165.1
Minus Nitrogen Plants				
Complete removal of top growth (close cutting)	11.8	3.6	0.52	15.9
Cut back to 1 inch	27.0	6.2	3.7	36.9
Cut back to 3 inches	38.8	9.7	8.8	57.3
Cut back to 6 inches	63.4	22.9	22.3	108.6
Cut back to 8 inches	58.6	29.0	28.0	115.6
Initial check (plants harvested before cutting was begun)	33.0	14.9	27.8	75.7
Final check (plants left uncut and harvested at end of experiment	56.7	30.0	27.6	114.3

check of the minus nitrogen treatment. In the plus nitrogen cultures the total plant weight was greatest in final check cultures; less in 8- and 6-inch cutting treatments.

Rhizomes from cultures receiving nitrogen were much higher in nitrogen than rhizomes from cultures receiving no nitrogen, as shown in Table 3. In the plus nitrogen cultures, rhizomes from the 1-inch cutting treatment were highest in nitrogen. In minus nitrogen cultures, rhizomes from the close-cutting treatment were higher in nitrogen than those from any other cutting height and the final check. Rhizomes from the final checks in the plus nitrogen cultures were higher in nitrogen than the initial checks, while in the minus nitrogen cultures the opposite was true; here the initial checks were highest in nitrogen. The rhizomes lowest in percentage of nitrogen at the conclusion of the experiment were those from cultures where the rhizome weight had been maintained about constant.

TABLE 3.—*Percentage total nitrogen on dry basis in quack grass rhizomes from plus and minus nitrogen cultures subjected to various cutting treatments.*

Treatment	Total nitrogen (dry basis)*	
	Plus N cultures, %	Minus N cultures, %
Completely defoliated	—	1.05
Cut back to 1 inch	2.12	0.65
Cut back to 3 inches	1.69	0.64
Cut back to 6 inches	1.74	0.71
Cut back to 8 inches	1.76	0.75
Initial check	1.81	1.18
Final check	2.00	0.87

*Analyses for nitrogen were made by the Section of Agricultural Chemistry, Michigan State College, East Lansing, Mich.

DISCUSSION

This experiment indicates that quack grass is influenced markedly by differences in defoliation and application of nitrogen.

Plus nitrogen quack grass cultures which were completely defoliated once a week had very few living shoots remaining after 24 weeks. Conversely, plants completely defoliated once each week and receiving no nitrogen were still producing many shoots after an equal period of cutting. In the minus nitrogen cultures the rhizome and root weight was about one-third as great as that of the initial checks while under the same conditions plus nitrogen plants were dead. Cutting cultures to 1 inch once a week was very injurious to plus nitrogen plants but caused only small injury to minus nitrogen plants. When plants receiving a continuous nitrogen supply were cut back to 3 inches, a loss in weight of rhizomes, roots, and tops resulted when compared to the initial checks. In a comparable treatment of minus nitrogen plants, there was a slight gain in rhizome weight, some loss of root weight, and a large loss in top weight.

Applications of nitrogen stimulated a vegetative response, resulting in more top growth. When this top growth was repeatedly removed by complete defoliation, the plant drew on its organic reserves to produce

new leaves. This treatment resulted in carbohydrate starvation and death of the plants.

Quack grass cultures in these experiments, however, were very conservative in their response to complete defoliation and heavy nitrogen applications since plants receiving an abundance of nitrogen with little or no opportunity for carbohydrate synthesis survived up to 24 weeks.

A further effect of nitrogen applications and repeated defoliations was noted in the total average dry weights of cultures from the various cutting treatments. In the plus nitrogen series the total average dry weight of cultures in the 6-inch cutting treatment was nearly equal to that of the initial check. In this treatment, however, the average rhizome weight was about one-third greater than that of the initial checks. In the plus nitrogen 3-inch cutting treatment, the average rhizome weight was less than that of the initial check. Considering these facts, it seems probable that the balance between vegetativeness and carbohydrate storage, as indicated by rhizome response, was somewhere between the 3- and 6-inch cutting treatments. On the other hand, this balance in the minus nitrogen cultures was between the 1- and 3-inch cutting treatment. As will be noted, the rhizome weight of the initial checks was about midway between the rhizome weights of the 1- and 3-inch cutting treatments.

Cutting the tops of minus nitrogen plants at 6 inches allowed for approximately maximum development of total plant weight. In plus nitrogen plants, however, maximum plant weight was produced in the uncut or final check plants.

In 24 defoliations, the plus nitrogen cultures cut at the 6-inch level produced but little more total dry matter than did the plus nitrogen close-cut cultures. The close-cut cultures were virtually killed by the end of 24 weeks but produced more recovery growth during the first part of this period than did the 6-inch cutting cultures.

A plus nitrogen quack grass culture given ample opportunity for photosynthesis tends to store organic food reserves rather than use all of the newly synthesized products in the production of new top growth.

In the minus nitrogen cultures, the amount of recovery growth produced by the close cutting treatment was almost twice that produced by the next highest or 1-inch cutting during the duration of the experiment. From this it would appear that to obtain maximum production of top growth under extreme minus nitrogen conditions, extreme defoliations would be necessary. Cultures under this cutting treatment lost about two-thirds of their total rhizome and root weight when compared to the initial checks.

Minus nitrogen plants grown with moderate defoliation tended to store carbohydrate reserves more readily than did plus nitrogen plants correspondingly defoliated. Productivity of new top growth diminished rapidly as the experiment progressed in all but the close cutting treatment in the minus nitrogen series.

The rhizomes of minus nitrogen plants increased in weight under a more severe cutting treatment than did plus nitrogen plants. Further, the production of new top growth at a 1-inch cutting or longer was

much smaller in minus nitrogen cultures than under similar cutting treatment of cultures receiving nitrogen. Nitrogen became the limiting factor in leaf production of the minus nitrogen cultures cut to 1 inch or longer. Under the close cutting treatment of the minus nitrogen series, it is probable that the plants were able to obtain enough nitrogen from the dying roots and rhizomes to produce the fairly high recovery growth.

In the close cutting treatments the dry weight of rhizomes at the beginning of the experiment was almost the same in both the plus and minus nitrogen quack grass cultures. The plus nitrogen cultures had produced a slightly higher recovery growth at the end of 24 weeks. However, at the conclusion of the experiment the plus nitrogen plants were nearly all dead while the minus nitrogen plants still had about one-third of the original dry weight of rhizomes left. This is evidence that low nitrogen plants utilize carbohydrate reserves at a slower rate and will eventually produce more top growth, provided cutting treatments are carried on over a sufficient period of time.

SUMMARY

1. After being defoliated completely once a week for 24 weeks, quack grass cultures receiving a continuous supply of nitrogen had very few functional shoots.

2. Cultures receiving no nitrogen and defoliated once a week for an equal period of time were still growing steadily.

3. Cutting cultures to 1 inch once a week was very injurious to plus nitrogen plants but caused only slight injury to minus nitrogen plants.

4. Plus nitrogen cultures cut to 3 inches lost in rhizome, root, and top weight. In minus nitrogen cultures receiving comparable defoliation the rhizome weight increased, there was some loss of root weight, and a large loss in top weight.

5. Minus nitrogen quack grass plants stored organic reserves in subterranean parts at a more severe cutting level than did plus nitrogen plants.

6. Plus nitrogen cultures completely defoliated once a week produced approximately as much recovery growth over a period of 24 weeks as did cultures cut back to 6 inches but at the expense of previously stored reserves.

7. Minus nitrogen cultures completely defoliated once a week produced only slightly less recovery growth than did plus nitrogen cultures receiving the same cutting treatment, and produced about twice as much as the next highest minus nitrogen cutting treatment.

8. Insofar as these greenhouse studies may be considered indicative of the growth habits of quack grass under field conditions, they indicate that the fertilization of quack grass should give an increase in top growth which could be used for hay or pasture and that subsequent control measures on quack grass thus fertilized should prove less difficult.

LITERATURE CITED

1. DEXTER, S. T. Response of quack grass to defoliation and fertilization. Plant Physiol., 11:843–851. 1936.
2. GRABER, L. F. Food reserves in relation to other factors limiting the growth of grasses. Plant Physiol., 6:43–72. 1931.
3. GRABER, L. F., NELSON, N. T., LEUKEL, W. A., and ALBERT, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial subaceous plants. Wis. Ag. Exp. Sta. Res. Bul. 80. 1927.
4. HARRISON, CARTER M. Effect of cutting and fertilizer applications on grass development. Plant Physiol. 6:669–684. 1931.
5. THOMAS, WALTER. Composition of current and previous season's branch growth in relation to vegetative and reproductive responses in *Pyrus Malus* L. Plant Physiol. 7:391–447. 1932.

NOTE

PRESERVING LONG-TIME EXPERIMENTS IN CEMENT FRAMES[1]

AGRICULTURAL experiment stations are continually faced with the problem of whether to continue certain long-established field plats or to make the areas available for what appears to be more pressing current problems. This is especially true with long-established soil fertility plats. When experiments have been continued over a period of 40 or 50 years, there is always great hesitancy about discontinuing them in favor of new projects. The question usually arises whether or not one may be discarding valuable material on soil conditions that have been developed over this long period of years, and which might be of inestimable value in some future work. After all, a continuous history of 50 years on a given area cannot be accumulated in less time than that. Usually, however, the old experiments have to give way to new projects due to limits of funds and available space.

At the Rhode Island Agricultural Experiment Station it was found a few years ago that so much of the total available area was being used for continuing long-established soil fertility and crop rotation plats that it was becoming increasingly difficult to find adequate space for new projects. Some of the rotation experiments were terminated, but many of the soil fertility plats were considered too valuable in accumulated history to be discontinued. The thought then occurred that it might be possible to preserve certain of these plats in miniature by using a fairly large sample of soil from each in small cement-bordered soil frames.

Among the plats with a continuous history over a considerable period of years was a 30-year comparison of manure-alone versus chemicals-only for vegetable crops. When the comparison was begun, this question seemed of much more importance than it does today. Although this would not be considered a practical problem at present, certain soil conditions have been produced in these plats that may serve a very useful purpose in future studies on soil organic matter. It seemed desirable to preserve an adequate sample of these plats, although it did not seem worth while to continue these on a field plat scale.

Other plats deemed worthy of perpetuating on a smaller scale were a 40-year comparison of several phosphorus carriers, a similar comparison of various amounts of potash and of nitrogen, a 35-year comparison of cover crops in continuous corn culture, and individual plats that had shown definite indications of deficiencies in either magnesium, manganese, phosphorus, potash, or nitrogen. The greater number of these plats are being continued, but the smaller plats are now established so there will not be as great hesitancy in discontinuing some of these should this become desirable.

[1]Published by permission of the Director of Research, Rhode Island Agricultural Experiment Station, as Contribution No. 533. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1938.

A series of 36 cement soil frames was constructed in the fall of 1934 similar to those that have been in use at the Cornell experiment station for many years.[2] Each frame is 1/1000 acre in area. The soils from the various plats were thoroughly mixed and placed in the frames in two 8-inch layers. A general view of these frames is shown in Fig. 1. Both the upper 8-inch layer and the lower 8-inch (subsoil) layer were obtained from sampling the original plat in a number of places. It was felt that the soil sample was representative of the entire plat.

The fertilizer applications used on the original plats have been continued on the frames. With the exception of the continuous corn frames, where corn has been continuously grown, a crop of potatoes,

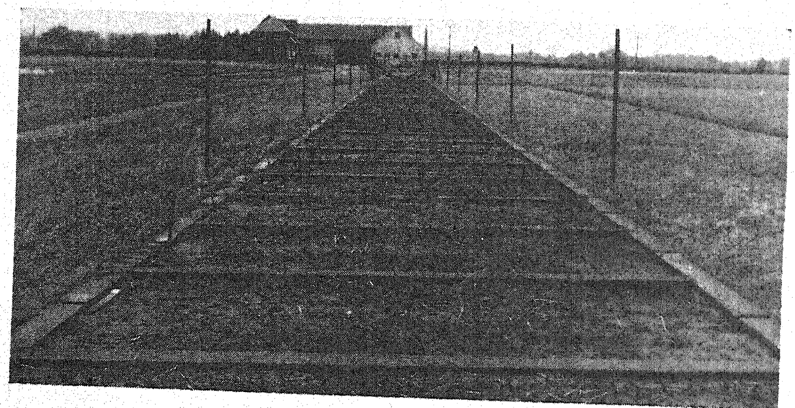

FIG. 1.—General view of cement frames at Rhode Island Agricultural Experiment Station.

one of corn, and one of soybeans have been grown since the frames were installed. In the spring of 1938 the plats were seeded to a legume-grass mixture with oats as a nurse crop. The yields obtained have been compared with those obtained on the original plats during recent years and a high correlation is found. These soil-filled cement frames therefore seem to lend themselves very well to the purpose for which they are being used. Although many of the original plats have now been discontinued, the Rhode Island Experiment Station still has a sufficient sample of the original, not only to continue obtaining similar information to that originally obtained, but also has a large enough sample on hand to use for other purposes such as chemical determinations.

These cement frames have been found particularly interesting to visitors at the experimental plats. It is possible to conduct a visitor or a small party to these frames and in a few minutes point out to them the symptoms of various soil deficiencies on growing crops, the effect of long-continued use of various fertilizers, and other experi-

[2]LYON, T. L., and LELAND, E. W. Artificial plats for field experiments. Jour. Amer. Soc. Agron., 18:596–602. 1926.

mental work. It is much more quickly accomplished and usually with more satisfaction than if a tour of the larger plats exhibiting similar conditions is made.

The method here described for continuing certain long-time experiments in miniature plats is recommended for consideration where problems of limited funds and space are confronted as was the case at the Rhode Island Experiment Station.—T. E. ODLAND and G. F. LEA, *Rhode Island Agricultural Experiment Station, Kingston, R. I.*

BOOK REVIEWS

THE STRUCTURE OF ECONOMIC PLANTS

Herman E. Hayward. New York: The Macmillan Company. X + 674 pages, illus. 1938. $4.90.

THIS book, long awaited and modest in price for the size and abundance of material which it contains, is an outgrowth of the course in plant anatomy given by the author at the University of Chicago. It attempts to bring together valuable anatomical work which has been done in the form of monographs on specific plants, many of them dealing with restricted phases of a particular plant as studies incidental to research in physiology, pathology, pharmacology, and other fields of plant science. These have been combined so as to present a thorough and complete story about the following important economic plants: Corn, wheat, onion, hemp, beet, radish, alfalfa, pea, flax, cotton, celery, sweet potato, white potato, tomato, squash, and lettuce.

Although each plant is discussed in detail, a nice distinction in emphasis is made for each crop by discussing most fully the special features which make that crop of economic significance. For example, the discussion of hemp emphasizes the structure of the stem and devotes a section to pericyclic fibers, while the discussion of the beet emphasizes the fleshy axis, secondary thickening, and tertiary thickening.

The book is in two parts, Part I, of 109 pages, dealing with general plant anatomy, and Part II with particular plants. It is well illustrated with outline drawings and photographs and contains an adequate bibliography and a helpful glossary. The point of view throughout is that of developmental anatomy and as such will be found of special value because of its relation to studies of physiology and experimental morphology. It should find wide appeal. (H. B. T.)

COMMERCIAL FERTILIZERS, THEIR SOURCES AND USE

By Gilbeart H. Collings. Philadelphia: P. Blakiston's Son and Co., Inc. Ed. 2. XVII+456 pages, illus. 1938. $4.00.

THIS is the second edition of this excellent book on commercial fertilizers. Like the former edition of 1934 it presents the most recent authentic information for anyone interested in growing larger yields of crops through the use of fertilizers, as well as being a guide for fertilizer manufacturers and a textbook for students of the subject.

The material is revised and brought up to date, a very essential requirement in this rapidly changing field, and the book is also enlarged by some 100 pages. New trends in fertilizer manufacture and use are gone into in some detail as well as new concepts of soil fertility and crop nutrition. Much new material is presented in the field of minor elements as well as on the problems of adjusting soil reaction and fertilizer practice to crop requirements.

The new volume contains a much enlarged bibliography of 385 titles and an author and subject index. Anyone who found the first edition useful will welcome this still more complete and comprehensive revision. (R. C. C.)

COTTON

By H. B. Brown, New York: McGraw-Hill Book Co., Inc. Ed. 2. XIII + 592 pages, illus. 1938. $5.00

ALTHOUGH synthetic fibers are making a strong bid for recognition, cotton is still the most important source of raw material in the textile world. How long this remains so depends upon the progress which will be made in the immediate future in cotton production and the use of the fiber. If the extensive program of cotton improvement in the United States is to go forward, more extensive and more thorough instruction must be given by our universities and colleges in the factors of production, particularly those affecting the quality of the fiber. Those who are responsible for this instruction, as well as the cotton grower and breeder, will welcome this second edition of H. B. Brown's "Cotton", the most comprehensive text dealing with this crop.

In general, it may be said that the entire book has been brought up to date. Although no new chapters have been added, the 25 chapters of the first edition have been revised to the limit of the new knowledge made available by recent cotton research, increasing the total number of pages from 517 to 592.

From the reviewer's point of view, the most urgent problems in the entire field of cotton investigation are those relating to the physiology of the plant, properties of the raw fibers, and the breeding of improved varieties. In the chapter on the physiology of the plant, new discussions have been added regarding the relation of water supply to development, temperature to yields, varietal differences with regard to absorption of soil solutions, the various factors affecting earliness, and others. Under fibers the new work on the development of the cotton fiber is reported. Also the difficult process of separating and measuring the different class lengths of the fibers in a ginned sample is described as well as the Suter-Webb cotton fiber sorter by which the fibers are separated into their various class lengths.

A valuable addition to this discussion, particularly for the breeder, would have been a description of some of the methods developed recently for length determinations of lint taken directly from the seed by length classes. In the chapter on breeding, asexual reproduction, defloration, acclimatization, and the delinting of planting seed are among the important items discussed. New knowledge has also been added to the chapter on fertilizers and rotations, diseases, and insects. In the chapter on spinning qualities, much information is given concerning the improvement of the quality of the fiber by means of better ginning and handling and by breeding and introducing improved varieties.

Ninety-five new references have been added. As the book now stands, it is indispensable as a text for students, a valuable help to

the investigator, and the best source of information for those who have a general interest in cotton. (W. E. B.)

AGRONOMIC AFFAIRS

THE HENRY STRONG DENISON GRADUATE FELLOWSHIPS IN AGRICULTURE AT CORNELL UNIVERSITY

THE BOARD OF TRUSTEES of Cornell University has announced the establishment of the Henry Strong Denison Graduate Fellowships in Agriculture, in memory of Henry Strong Denison, a graduate of Cornell University in the class of 1905. These fellowships were created by a gift from the Henry Strong Denison Medical Foundation, Inc., founded by Mrs. Ella S. Denison.

Three fellowships with an annual stipend of $1,000 each will be awarded in the fields of the plant sciences, animal sciences, and social sciences and agricultural engineering, for the purpose of encouraging young graduate students "who are especially gifted and qualified to carry on research work in the science of agriculture."

In awarding the fellowships, preference will be given to those applicants who expect to complete the requirements for the Ph.D. degree and who appear most promising from the standpoint of ability to conduct research. Blank forms of application may be obtained from the Dean of the Graduate School, Cornell University, Ithaca, N. Y., and all applications must be filed in the Office of the Graduate School before March 1, 1939.

THE NATURALIST'S DIRECTORY

THIS reference volume contains the names, addresses, and special subjects of study of professional and amateur naturalists in North and South America and other countries. The 1938 edition has just been published and is obtainable for $3.00, postpaid, from the Naturalist's Directory, Salem, Mass.

JOURNAL

OF THE

American Society of Agronomy

VOL. 31 FEBRUARY, 1939 No. 2

ALFALFA NURSERY TECHNIC[1]

H. M. TYSDAL AND T. A. KIESSELBACH[2]

WITH the development of numerous new strains of alfalfa requiring testing in various improvement programs, the results of an alfalfa nursery method study at the Nebraska Agricultural Experiment Station would seem of interest. The chief objective of these investigations has been to determine whether the yields and other data obtained from small nursery plats with low seed requirements are comparable with those from ordinarily accepted field plats.

Variations in nursery technic were studied with respect to such factors as number of rows per plat, distance between rows, alley space between plats, removal of border rows at harvest, interplat varietal competition, spacing of plants within the row, planting equal amounts of seed per row versus equal amounts per acre for the different row spacings, and plat distribution. The tests were made through comparable, adjacent plantings of two varieties, Hardistan and Ladak, which differ in growth habits and productivity. The relative yields of these two varieties under the various modes of testing are reported.

MANNER OF LAYING OUT THE TEST

The general planting plan of one complete replication, showing the plat distribution, number of rows per plat, and the row-spacing, is illustrated in Fig. 1. The plats were planted in eight beds of two complete replications each. Within a replication, similar types of plats of the two varieties were always placed adjacent to enable a direct study of differential varietal responses in the various plat types. Adjacent unlike plats were separated by suitable guard rows in order to provide the specific conditions required of the tests. Since there were eight beds and seven main types of nursery plats under comparison, the latter were so distributed in the beds that the same type of plat did not fall in the same strip or column more than once (with one exception), thus resembling in this respect a Latin square arrangement.

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station as Journal Series Paper No. 217. Received for publication November 10, 1938.

[2]Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Agronomist, Department of Agronomy, Nebraska Agricultural Experiment Station, respectively.

The 1/80-acre field plats adjacent to the nursery plats were sown with a standard 7-foot alfalfa drill which spaced the rows 4 inches apart. The rows of the nursery plats, sown with a 1-row Columbia garden drill, were all 16 feet in length but differed as to number and spacing. Variations in number of rows were 1, 3, 4, and 8 rows per plat, while the row spacings under comparison were 7, 18, and 24 inches. The locations of the two varieties, Hardistan and Ladak, are indicated in the diagram by solid and broken lines, respectively. The guard rows placed between the different spacings are also shown. These guard rows do not enter into any of the calculations on varietal yields, but are used to show the effects of row-spacing and thickness of stand on interplat competition. A total of 16 replications of each type of plat was planted.

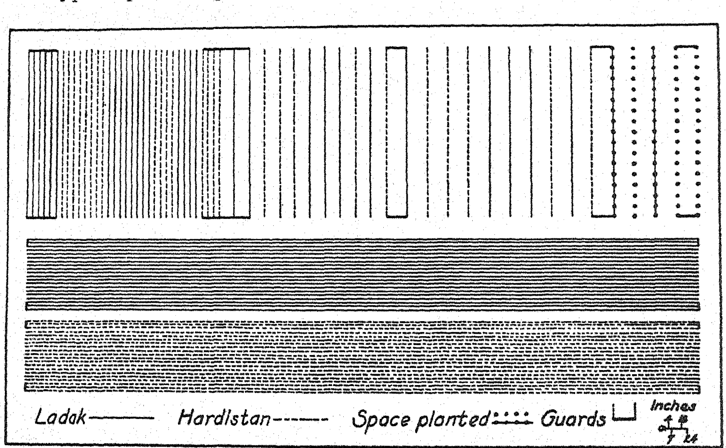

FIG. 1.—Planting plan of one complete replication of the alfalfa method study nursery. The nursery rows are represented in the upper part of the figure, while the two field plats are below. The entire distribution is drawn to scale; thus the spacings between rows are shown by the distance between the lines. The guards inserted between unlike spacings are shown by joining the ends of the guard rows with a heavy solid line. The two varieties, Ladak and Hardistan, are represented by solid and broken lines, respectively.

The various row spacings in nursery plats were compared with two rates of seeding, equal rates per row and equal rates per acre. While all the 7-inch rows were sown with 1.46 grams of seed per row or at the rate of 15 pounds per acre, only half of the 18- and 24-inch rows were seeded at this same rate per row (1.46 grams), which amounted to approximately 6 and 4 pounds per acre, respectively. The other eight replications of these two wider spacings were sown at the respective rates of 3.7 grams and 5.0 grams per row in order to provide equal rates per acre (15 pounds) corresponding with the 7-inch rows. The field plats also were planted at the rate of 15 pounds per acre.

The effect of additional alley space between nursery blocks was studied by increasing the distance between border rows of the 7-inch blocks to 12 inches in half the replications. In the other eight replications this distance was 7 inches, which provided no extra alley space.

All plats were solid-drilled with the exception of single, well-guarded rows spaced 24 inches apart which were sown lightly and thinned in the seedling stage so that the plants were spaced 12 inches apart in the row. These will be called the

"space-planted" in contrast with the "solid-drilled" rows. The entire test was sown in the spring of 1933 after fallow for one year.

NURSERY AND FIELD PLATS COMPARED

The plats were not cut in 1934, partly because of the drought but chiefly because it was desired to allow the plants to become thoroughly established before yields were taken. Three cuttings were obtained from all plats in 1935, but because of unusually severe drought only one cutting materialized in 1936 and one in 1937. In field plats in the three successive years, Hardistan yielded 5,981, 1,616, and 1,180 pounds of hay (15% moisture content) per acre, compared with 7,061, 2,037, and 1,520 pounds for Ladak. The superiority of Ladak amounted to 18, 26, and 29% in the different years. These annual yields from the field plats, together with those from the various kinds of nursery plats, are reported in Table 1. For the purpose of these comparisons the yields are calculated for the interior rows only in case of the multiple-row plats in order to avoid possible interplat competition effects as far as possible. Thus, the yields of 8-, 4-, and 3-row nursery plats are based on the 4, 2, and 1 middle rows, respectively, while a 4.5-foot swath was harvested from the middle of the 7-foot field plats.

In all types of plats the Ladak outyielded the Hardistan every year by a large and significant margin, though varying in amount. For the different types of plats, the following ratios for the 3-year average yields of Ladak to Hardistan, expressed in per cent, are found: Field plats, 4-inch spacing, 121; 8-row, 7-inch spacing, 127; 4-row, 7-inch spacing, 123; 3-row, 18-inch spacing, 125; 1-row, 18-inch spacing, 118; 3-row, 24-inch spacing, 125; 1-row, 24-inch spacing, 121; and 1-row, 24-inch spacing, space-planted, 128. Corresponding ratios for the favorable year, 1935, were 118, 127, 123, 125, 119, 123, 118, and 121.

The extreme departure of the 3-year ratios of any of the four types of multiple-row nursery plats from that of the field plats was 6%. In single-row plats spaced 24 inches apart, the relative yields were the same as in field plats, while in the single rows spaced 18 inches the departure was 3%. In the space-planted rows the superiority of Ladak was 7% greater than in the field plats.

The statistical significance of these differences was determined by applying the analysis of variance to the yields of the middle rows of the multiple-row nursery plats and the field plats. The 1935, 1936, and 1937 yields of the 16 replicates of all types of plats shown in Table 1 having more than one row per plat were used. Thus five types of plats were compared and it was found that there was no significant interaction[3] of the varieties on the different plats studied, the

[3]Throughout this paper the term "interaction" is used in the following sense: Of two varieties A and B, suppose A yields 10% more than B under one set of conditions and only 5% more than B under a different set of conditions. This differential response is called "interaction" and can be studied by separating the different elements contributing to variation, as shown in Table 2. For example, in the following studies, Hardistan yielded relatively more compared with Ladak under certain conditions, chiefly due to competition effects. One of the problems is to determine if these differences in relative yields are statistically significant. In this paper significance is arbitrarily placed at the commonly accepted odds of 19 to 1.

TABLE 1.—*Effect of row and plant spacing upon the yield of two varieties of alfalfa.*

Kind of plat	Space between rows, in.	Spacing of plants	Rows per plat	Yield of forage per acre (15% moisture)*: Actual, lbs. Hardistan	Actual, lbs. Ladak	Relative, % Hardistan	Relative, % Ladak	Ratio Ladak to Hardistan yield, %
				1935				
Field	4	Solid	20	5,981	7,061	100	100	118
Nursery	7	Solid	8	7,206	9,118	120	129	127
Nursery	7	Solid	4	7,563	9,315	126	132	123
Nursery	18	Solid	3	7,292	9,113	122	129	125
Nursery	18	Solid	1	7,365	8,729	123	124	119
Nursery	24	Solid	3	6,871	8,466	115	120	123
Nursery	24	Solid	1	6,938	8,203	116	116	118
Nursery	24	12 inches	1	4,410	5,347	74	76	121
				1936				
Field	4	Solid	20	1,616	2,037	100	100	126
Nursery	7	Solid	8	1,822	2,278	113	112	125
Nursery	7	Solid	4	1,843	2,279	114	112	124
Nursery	18	Solid	3	1,737	2,157	107	106	124
Nursery	18	Solid	1	1,759	2,037	109	100	116
Nursery	24	Solid	3	1,645	2,109	102	104	128
Nursery	24	Solid	1	1,630	2,051	101	101	126
Nursery	24	12 inches	1	1,707	2,345	106	115	137
				1937				
Field	4	Solid	20	1,180	1,520	100	100	129
Nursery	7	Solid	8	1,196	1,548	101	102	129
Nursery	7	Solid	4	1,402	1,659	119	109	118
Nursery	18	Solid	3	1,294	1,672	110	110	129
Nursery	18	Solid	1	1,407	1,624	119	107	115
Nursery	24	Solid	3	1,192	1,525	101	100	128
Nursery	24	Solid	1	1,163	1,533	99	101	132
Nursery	24	12 inches	1	1,391	1,914	118	126	138
				Averages for 3 Years				
Field	4	Solid	20	2,926	3,539	100	100	121
Nursery	7	Solid	8	3,408	4,315	116	122	127
Nursery	7	Solid	4	3,603	4,418	123	125	123
Nursery	18	Solid	3	3,441	4,314	118	122	125
Nursery	18	Solid	1	3,510	4,130	120	117	118
Nursery	24	Solid	3	3,236	4,033	111	114	125
Nursery	24	Solid	1	3,244	3,929	111	111	121
Nursery	24	12 inches	1	2,503	3,202	86	90	128

*In the case of multiple-row plats, the yields are based on the interior rows only.

$\frac{\text{Mean square}}{\text{Mean square error}}$ equalling 1.24, while the 5% F value was 2.44 and the 1% F value, 3.46. Details of the analysis are shown in Table 2. A similar analysis made for the solid-drilled and space-planted single-row plats comparing them in each case with the field plats again gave no significant interaction between varieties and type of plat.

From these analyses the conclusion may be drawn that the several types of nursery plats gave essentially the same *relative* yields of the two varieties as did the field plats.

TABLE 2.—*Variance analysis of the yields from the interior rows of field plats and four types of multiple-row nursery plats, namely, 8-row, 7-inch spacing; 4-row, 7-inch spacing; 3-row, 18-inch spacing; and 3-row, 24-inch spacing, 16 replications, average of 1935, 1936, and 1937 crops.*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value*
Varieties	1	25,525,684	25,525,684	—
Replications	15	12,740,405	849,360	—
Type of plat	4	12,198,312	3,049,578	—
Interaction:				
Variety × type of plat	4	449,911	112,478	1.24
Error: Variety × replication	15 } Total 135	12,244,196	90,698	—
Error: Replication × type of plat	60			
Error: Variety × rep. × type of plat	60			
Total	159	63,158,508		

*The F values for the 5 and 1% points, respectively, are 2.44 and 3.46 as obtained from Snedecor, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934. (Pages 88–91.)

INTERPLAT COMPETITION AND ALLEY SPACE EFFECTS

Since the two varieties, Hardistan and Ladak, were planted alternately in both single- and multiple-row plats, and since all rows were harvested individually for yield determination, it was possible to calculate the extent to which yields were modified by interplat competition and alley space. This was done through a comparison of yields based on the interior rows, which are regarded as relatively free from interplat competition and other marginal effects. The data are reported in Table 3. The results for 1935 only are presented. The indications of that year were generally confirmed both in 1936 and 1937. The plants had become well established by 1935.

MULTIPLE-ROW PLATS

It will be recalled that half the plats with 7-inch row spacing were separated by only 7 inches between border rows (alley space), while the other half (eight replications) had a corresponding separation of 12 inches. The comparative effects of these two different spacings between plats is brought out strikingly in Table 3. Not only were the yields of the border rows materially higher for the 12-inch alley space, but the relative yield of the Ladak was greatly increased in the border rows. At the 7-inch spacing between 8-row plats, the border rows (rows 1 and 8) of Ladak yielded 108% of Hardistan, whereas in the middle rows it yielded 127% of Hardistan. Similarly, in the 4-row plats Ladak yielded 106% in the border rows compared to 126% in the interior rows. With a 12-inch alley space, the border rows (rows 1 and 8) of the Ladak in 8-row plats yielded 129% of the Hardistan, while in the 4 middle rows it yielded 126% of Hardistan. In the

border rows of the 4-row plats separated by a 12-inch alley space, the Ladak yielded 115% of Hardistan compared with 121% in the two middle rows.

TABLE 3.—*Relative yields of two alfalfa varieties differing in growth habits when compared in alternating nursery plats differing as to row number, plant and row spacing, and portion harvested, 1935.*

Portion of plat considered	Yield of forage per acre (15% moisture): Actual, lbs. Hardistan	Actual, lbs. Ladak	Relative, %* Hardistan	Relative, %* Ladak	Ratio Ladak to Hardistan yield, %
7-inch Spacing Between Rows					
8-row plats, average for plats having 7 and 12 inches between border rows of adjacent plats:					
4 middle rows	7,206	9,118	100	100	127
Rows 2 and 7	7,622	9,304	106	102	122
Rows 1 and 8†	8,800	10,537	122	116	120
Entire plat	7,593	9,434	105	103	124
8-row plats, 7 inches between border rows:					
4 middle rows	7,362	9,333	102	102	127
Rows 2 and 7	7,457	9,111	103	100	122
Rows 1 and 8	7,961	8,622	110	95	108
Entire plat	7,429	9,100	103	100	122
8-row plats, 12 inches between border rows:					
4 middle rows	7,049	8,903	98	98	126
Rows 2 and 7	7,786	9,496	108	104	122
Rows 1 and 8†	9,638	12,389	134	136	129
Entire plat	7,757	9,767	108	107	126
4-row plats, 7 inches between border rows:					
2 middle rows	7,380	9,293	102	102	126
Rows 1 and 4	8,026	8,504	111	93	106
Entire plat	7,703	8,899	107	98	116
4-row plats, 12 inches between border rows:					
2 middle rows	7,745	9,337	107	102	121
Rows 1 and 4†	9,900	11,380	137	125	115
Entire plat	8,823	10,359	122	114	117
4-row plats, average for plats having 7 and 12 inches between border rows:					
2 middle rows	7,563	9,315	105	102	123
Rows 1 and 4†	8,963	9,942	124	109	111
Entire plat	8,263	9,629	115	106	117

*The relative yields are based on the actual yields from the four middle rows of all 8-row plats in which the rows were spaced 7 inches apart.

†The actual area occupied by these border rows spaced 12 inches apart is 36% greater than that of the interior rows. The acre yield as indicated, however, is calculated on the same area basis as interior rows.

TABLE 3.—*Concluded.*

Portion of plat considered	Yield of forage per acre (15% moisture)				Ratio Ladak to Hardistan yield, %
	Actual, lbs.		Relative, %*		
	Hardistan	Ladak	Hardistan	Ladak	
18-inch Spacing Between Rows					
3-row plats:					
Middle row	7,292	9,113	101	100	125
Rows 1 and 3	7,289	8,921	101	98	122
Entire plat	7,339	8,985	102	99	122
1-row plats:					
Single row	7,365	8,729	102	96	119
24-inch Spacing Between Rows					
3-row plats:					
Middle rows	6,871	8,466	95	93	123
Rows 1 and 3	6,944	8,380	96	92	121
Entire plat	6,914	8,418	96	92	122
1-row plats:					
Single row	6,938	8,203	96	90	118
1-row plats, space planted, 12 inches between plants:					
Single row	4,410	5,347	61	59	121

*The relative yields are based on the actual yields from the four middle rows of all 8-row plats in which the rows were spaced 7 inches apart.

With such striking differential response of varieties to border competition when grown in multiple-row plats with rows spaced as close as 7 inches, it would seem highly important to base varietal yields in such plats on the interior rows only. By widening the alley space between adjacent plats of this type from 7 to 12 inches this differential interplat competition was largely eliminated and was not found statistically significant.

Of further interest is the fact that in closely-spaced rows the higher-yielding variety, Ladak, is depressed by competition with the lower-yielding variety, Hardistan. This may perhaps be partly explained by the fact that Hardistan generally recovers more quickly after cutting than Ladak and also has a tendency to grow slightly taller in all but the first cutting. As an average of from 8 to 15 readings the following heights have been recorded for Ladak and Hardistan at the time of cutting: 1st cutting, Ladak 18.80 inches, Hardistan 18.66 inches; 2nd cutting, Ladak 17.25, Hardistan 20.91; 3rd cutting, Ladak 10.92, Hardistan 15.53 inches.

In the case of multiple-row plats with widely spaced rows, the degree of interplat varietal competition was very slight and not statistically significant. With 18-inch row spacing, Ladak yielded 125% of Hardistan in the middle rows and 122% in the border rows.

With 24-inch spacing, Ladak yielded 123% in the middle rows and 121% in the border rows. Such small border competition effects might perhaps be ignored in most varietal comparisons made in this type of plat.

SINGLE-ROW PLATS

The data from alternating single-row plats of Hardistan and Ladak alfalfa spaced 18 and 24 inches apart are contrasted (Tables 1 and 3) with the middle rows of corresponding 3-row plats.

The superiority of Ladak in 18- and 24-inch, single-row plats was 7% and 4% less, respectively, as a 3-year average than in the middle rows of corresponding 3-row plats. This suggests an appreciable degree of interplat competition between the single 18-inch rows but less for the 24-inch spacing. For the favorable year 1935, the superiority of Ladak was 6 and 5% less, respectively, in the single 18- and 24-inch rows than in the interior rows of corresponding 3-row plats, suggesting some interplat competition for single rows of both spacings, though the effects were not statistically significant.

STATISTICAL SIGNIFICANCE OF COMPETITION EFFECTS

The variance analysis, similar to that presented in Table 2, shows the interaction to be significant between the border rows and middle rows of the 8-row and 4-row plats that were separated by a 7-inch alley space, the significance being above the 1% point in both cases. The interaction in the same types of plats with 12 inches alley space was not significant. In other words, there was a great deal of varietal competition across a narrow 7-inch alley space, resulting in a differential yield of the two varieties but not sufficient competition with the wider, 12-inch alley to change significantly their relative yields.

In calculating the interaction of the 18-inch spacing the 3-row and 1-row plats were considered separately. The middle rows of the 3-row blocks were compared with the border rows and also with the alternating single-row plats. Neither interaction was statistically significant.

The plats with rows spaced 24 inches apart were analyzed in a similar manner, and again, neither the border rows of the 3-row plat nor the single alternate rows differed significantly from the center row of the 3-row plat.

These analyses indicate that under the conditions of this experiment there was significant varietal competition between the border rows when spaced 7 inches apart. When the border rows were spaced 12 inches, or more, there was no statistically significant modification of comparative varietal yields through interplat competition.

EFFECT OF ALLEY SPACE ON YIELD OF NURSERY PLATS

That the yield of alfalfa responds to variations in the width of alley space (distance between border rows) separating nursery plats is shown in Table 3 for those plats in which the rows were 7 inches apart. As an average for two varieties, in 8-row plats, the border rows yielded the same as the four middle rows when the alley space was 7 inches, whereas they yielded 36% more when the alley space was 12

inches. Since the area occupied by the row increased 35.7%, the increase in yield corresponded very closely with the increase in area. Rows 2 and 7 were also affected by the competition, yielding 7% more than the four middle rows. This border effect caused the entire plat to yield 9% more in response to 5 inches of added alley space which was an increase of 9% in plat area.

In a similar test with 4-row plats, the border rows yielded the same as the middle rows when the alley space was 7 inches, while they yielded 31% more when the alley space was widened to 12 inches. This border effect caused the entire plat to yield 14% more in response to the 5 inches wider alley space which was an increase of 18% in plat area. Since the border rows of plats respond favorably to increased alley space, such additional space should preferably be included in the area of the plats when acre yields are calculated.

SPACE-PLANTED ROWS

Although the actual acre yield was far lower in 1935 for the space-planted rows, the relative yields of the two varieties tested were nearly the same as for the close-drilled field plats. In the two succeeding years, when the plants had become better established and the crop suffered more from moisture deficiency, the space-planted rows actually outyielded the field plats and the superiority of Ladak was somewhat greater than for any other type of field or nursery plat. This advantage of Ladak during the last two years probably may be accounted for by a more rapid crown growth (Table 6) which would enable it to occupy the land more completely. In general, space-planted nursery plats would seem somewhat less exact for varietal yield determinations than are solid-drilled plats.

MODIFICATION OF PLAT YIELDS BY ADJACENT UNLIKE PLATS

As a result of having determined the yield of the various guard rows, several illustrations are available of the striking border-row response to dissimilar adjacent plats differing as to spacing of rows or plants. The data are suggestive of the magnitude of the error that may occur if a hardy strain is growing in a nursery plat adjacent to one which has a very poor stand due to winterkilling or other causes. The yields of interior plat rows, which are relatively free from unlike competition, and of corresponding border rows are reported in Table 4.

The first comparison in the table is one of the most interesting. A solid-drilled block with 7-inch row spacing was separated by a 7-inch alley space from a space-planted block with rows 24 inches apart. Of the adjacent border rows when compared with their respective types of interior rows, the solid-drilled row gave an excess yield of 74% because of reduced competition on one side, whereas the space-planted row was depressed 63% in yield because of increased competition.

The other comparison in Table 4 is between two rows spaced 18 inches apart, one of which was the last row of a multiple-row plat with 7 inches between its rows, while the other was the first row of a multiple-row plat with 18 inches between its rows. The row with 7-

inch spacing on one side and 18 inches on the other exceeded the yield of the interior rows of the 7-inch spacing by 87%. On the other hand, the row with 18-inch spacing on one side and the plat having 7-inch spacing at a distance of 18 inches on the other was reduced 7% in yield compared to the interior row of 18-inch spacing.

TABLE 4.—*Border competition between nursery plats differing as to spacing of rows or plants.**

Description of competing plats				Yield of forage per acre (15% moisture)					
Plats on which yields are reported		Adjacent modifying plats		Actual, lbs.			Relative, %		
Space between rows, in.	Type of planting	Space between rows, in.	Type of planting	First border row	Second border row	Interior row	First border row	Second border row	Interior row
Adjacent Plats Separated by 7-inch Alley Space									
7	Solid	24	Spaced	15,840	10,361	9,118	174	114	100
24	Spaced	7	Solid	1,616	3,802	4,410	37	86	100
Adjacent Plats Separated by 18-inch Alley Space									
7	Solid	18	Solid	13,455	8,257	7,206	187	115	100
18	Solid	7	Solid	8,503	8,827	9,113	93	97	100

*The two varieties, Ladak and Hardistan, were adjacent in this test, but the varietal competition played a very minor rôle, being less than 10% in the 7-inch spacing and not greater than 2% in the 18-inch spacing.

Similar effects may be illustrated as follows from data not shown in the table: When two rows were spaced 24 inches apart, one of which was the last of an 18-inch spacing and the other was the first of a 24-inch spacing, the yield of the former was increased 9% and that of the latter was reduced 6% as compared with comparable interior rows. Wherever a slight opportunity is afforded for expansion, the plants are quick to take advantage of it. Perhaps this is particularly true where there is relatively severe competition for soil moisture.

The data also give some indication as to how many marginal rows of a plat are affected by border competition. In the case of the second border row in the solid-drilled 7-inch spacing, the excess yield resulting from lowered competition with adjacent space-planted alfalfa amounted to only 14%, compared with 74% for the outside border row. Yields obtained in 1937 on the third and fourth rows from the border indicate little carryover of the effect into the third row, which was only a total of 14 inches from the border. It seems evident that great care must be exercised in taking yields from rows which are apt to be either at an advantage or a disadvantage with respect to spacing of rows or density of stand.

RATE OF SEEDING NURSERY PLATS

As previously indicated, half of the plats with 18- and 24-inch row spacing were sown to the same amount of seed per row as the 7-inch rows, while the other half were sown at equal amounts of seed per acre. The amounts of seed per acre were approximately 4, 6, and 15 pounds for the 24-, 18-, and 7-inch rows when sown at equal amounts per row, whereas 15 pounds per acre was the uniform rate when all spacings were sown at equal rates per acre. The yields from these tests are given in Table 5.

TABLE 5.—*Comparative yields in 1935 of Hardistan and Ladak alfalfa when seeded at equal rates per row versus equal rates per acre in nursery test plats differing as to row spacing; yield based on the interior rows relatively free from border competition.*

Space between rows, in.	Rows per plat	No. interior rows harvested	Yield of forage per acre (15% moisture) when equal amounts of seed are sown per: Row			Acre			Ratio yield row basis to acre basis	
			Hardistan, lbs.	Ladak, lbs.	Ratio Ladak to Hardistan, %	Hardistan, lbs.	Ladak, lbs.	Ratio Ladak to Hardistan, %	Hardistan, %	Ladak, %
7	8	4	7,206	9,118	127	7,206	9,118	127	100	100
18	3	1	7,493	9,588	128	7,089	8,638	122	106	111
24	3	1	7,041	8,754	124	6,701	8,179	122	105	107

Increasing the amount of seed per row in the two wider spacings in order to provide equal seeding rates per acre proved a slight disadvantage for both varieties as reflected by somewhat lower yields per acre. This reduction ranged from 5 to 11%.

As to effect on the relative yield of the two varieties, Ladak yielded 27, 28, and 24% more than Hardistan in the 7-, 18-, and 24-inch spacing, respectively, when seeded at equal rates per row, compared with 27, 22, and 22% superiority when seeded at equal rates per acre. Assuming that the relative yields of the two varieties in the 7-inch spacing most nearly represent true farm performance, the departure was only 1 and 3%, respectively, in the 18- and 24-inch spacings when planted at equal rates per row and 5% for both spacings when sown at equal rates per acre.

It is concluded that there may be considerable latitude in the amount of seed sown in rows spaced various distances apart. When the spacing between rows materially exceeds 7 inches, however, it seems preferable to approximate the 1.5 grams of seed per 16-foot row as required in 7-inch spacing planted at 15 pounds per acre.

RATE OF SEEDING IN RELATION TO SUBSEQUENT STAND AND CROWN SPREAD

The plats concerned in these method studies were plowed in March, 1938, and this afforded an opportunity to make counts on the actual

number of plants surviving per row. The crown spread at the surface of the ground was also determined for 10 or more rows of both varieties in each type of plat.

Table 6 is a summary of the counts and measurements, each figure for the number of plants per acre being an average of at least eight counts of the number of roots made at the edge or bottom of the furrow. This method of counting has been found much more accurate than trying to count the number of plants at the surface of the ground.

TABLE 6.—*Number of plants per row and per acre and crown spread at surface of ground in 1937 as related to the rate of seeding in different types of plats in 1933.*

Kind of plat	Space between rows, in.	Rate of seeding		Number of plants per acre		Crown spread		
		Per acre, lb.	Per 16-ft. row, grams	Hardistan	Ladak	Hardistan, in.	Ladak, in.	Ratio Ladak to Hardistan, %
Field	4	15	0.84	500,300	504,100	2.41	2.57	106.6
8-row	7	15	1.46	686,100	658,100	3.00	3.29	109.7
3-row	18	15	3.70	473,700	446,500	4.61	4.50	97.6
3-row	18	6	1.46	377,500	361,200	4.75	4.97	104.6
3-row	24	15	5.00	296,800	349,800	4.53	4.86	107.3
3-row	24	4	1.46	310,400	264,100	4.89	5.36	109.6
1-row	24	sp. pl.	17 pls.	25,179	26,540	6.18	7.43	120.2

The type of plats together with the rate of planting is also given in Table 6. From a comparison of the 3-row blocks spaced 18 and 24 inches between the rows, it is obvious that the variation in the original rate of seeding made in 1933 did not have a great influence on the number of plants found in the spring of 1938. Natural competition doubtless accounts for this equalization in number of plants since both varieties are winter hardy. This lends weight to the conclusion that there may be a fairly wide range in rate of seeding, provided a sufficiently good stand is obtained.

An interesting feature of the results presented in Table 6 has to do with the relative crown spread of the two varieties. As an average in the solid-drilled rows Ladak had from 2.4% less to 9.7% greater spread of crown than Hardistan, but in the space-planted material (one plant per foot) Ladak had a 20.2% greater spread. This greater crown spread may account for the increased yield of Ladak over Hardistan under space-planted conditions, amounting to 11 and 9% (Table 1) above the solid-drilled field plats in 1936 and 1937, respectively. This also leads to the important conclusion that differential response of varieties in occupying the land may lead to a fundamental error in space-planted yield tests of alfalfa.

EFFECT OF AREA OF FIELD INCLUDED IN TEST UPON VARIABILITY OF NURSERY YIELDS

Variability studies of yields of similar plats combining various areas in the nursery resulted in finding significantly less variability

within small areas as compared with larger areas. This again emphasizes the desirability of keeping the land area as small as possible after considering other necessary factors.

NUMBER OF REPLICATIONS OF THE DIFFERENT PLAT TYPES REQUIRED TO MAKE A 5% DIFFERENCE IN YIELD STATISTICALLY SIGNIFICANT

Table 7 has been prepared to give the standard deviations of all types of plats based on the mean yields for the three years 1935, 1936, and 1937. The mean yields are also given and the standard errors in per cent of the mean. Two further columns are added, the first giving the number of replications required to make a 5% difference in yield statistically significant and the second based on calculations similar to those made by Immer[4] showing the relative efficiency of the land with different types of plats.

The number of replications required to make a 5% difference in yield statistically significant is obtained by multiplying the standard error in per cent of the mean by $\sqrt{2}$ to obtain the standard error of a difference, multiplying this by 2 for the conventional minimum level of significance, then dividing this total by 5, which is the assumed percentage difference in yield. This figure is the value of the $\sqrt{n}$, which, when squared, gives the number of replications required. The equation for the field plats becomes $\frac{3.3\sqrt{2} \times 2}{\sqrt{n}} = 5$(per cent difference in yield), where n is the number of replications required.

The results of these calculations indicate that there is a wide difference in the number of replications required for a given level of significance, depending on the type of plat. As would be expected, the field plats show to advantage, requiring only 3.5 (4) replications, on the average, while the single space-planted rows 24 inches apart require 15.7 (16) replications to obtain the same accuracy. Other types of plats are intermediate, although they vary considerably, depending on the error involved. This variability emphasizes the fact that rigid conclusions regarding the number of replications cannot be drawn from one set of data; the results, however, indicate certain trends which should be considered in a decision as to the type of nursery plat to be used.

For the calculations of plat efficiency in the last column of Table 7, the area of land for each plat is taken into consideration as well as the number of replications required to obtain a statistically significant difference with a 5% difference in yield. It is obvious that in this calculation the smaller-sized plats have a distinct advantage provided the error is not too large. If, as in this case, the single-row plat, with rows spaced 18 inches apart, is arbitrarily considered 100%, all other types of plats are lower in land-use efficiency. These results, however, must be used with caution because other factors, such as

[4]IMMER, F. R. Size and shape of plat in relation to field experiments with sugar beets. Jour. Agr. Res., 44: 649-668. 1932

TABLE 7.—*Standard error and mean yield of different types of plats, the theoretical number of replications required to reduce the error to such a value that a 5% difference in mean yield of two varieties would be statistically significant, and the relative efficiency of the types of plats used, average of 1935, 1936, and 1937 crops.*

Kind of plat	Standard deviation, lbs.	Mean yield of two varieties, lbs.	Standard eror in per cent of mean	No. reps. required to make a 5% difference in yield statistically significant	Relative efficiency of plat, %
Field plats	107	3,233	3.3	3.5	12.2
Four middle rows of 8-row plat	167	3,861	4.3	5.9	47.0
All 8 rows of 8-row plat	163	4,075	4.0	5.1	54.3
Two middle rows of 4-row plat	247	4,010	6.2	12.3	45.4
All 4 rows of 4-row plat	192	4,268	4.5	6.5	85.9
Middle row of 3-row plat, 18-in. spacing	260	3,877	6.7	14.4	20.1
All 3 rows of 3-row plat, 18-in. spacing	167	3,848	4.3	5.9	48.7
Single-row plat, 18-in. spacing	198	3,820	5.2	8.6	100.0
Middle row of 3-row plat, 24-in. spacing	141	3,635	3.9	4.8	44.4
All 3 rows of 3-row plat, 24-in. spacing	136	3,638	3.7	4.4	49.4
Single-row plat, 24-in. spacing	163	3,586	4.6	6.8	95.9
Single-row plat, 24-in. spacing, space planted	199	2,852	7.0	15.7	41.4

ease of handling, competition, etc., require consideration. Further studies bearing on these problems under various conditions would be helpful.

SUMMARY

By appropriate plantings, alfalfa nursery plat technic was studied with respect to number of rows per plat, distance between rows, alley space between plats, removal of border rows at harvest, interplat varietal competition, spacing of plants within the row, rates of planting, and plat distribution.

Two varieties, Hardistan and Ladak, were compared in 16 replications of nine types of nursery plats and adjacent field plats. The nursery plats were 16 feet long with variations of 1, 3, 4, and 8 rows per plat, while the row-spacings under comparison were 7, 18, and 24 inches. All of these plats were solid-drilled except one group in which the plants were spaced 12 inches in rows 24 inches apart.

Yields were obtained during a 3-year period, 1935, 1936, and 1937, which analyzed comparatively and statistically indicated the following:

Solid-drilled plats with a 7-inch row spacing were definitely subject to serious interplat varietal competition. The effects of this could be overcome by discarding border rows at harvest. Widening the alley space between plats to 12 inches also prevented a significant interaction between varieties. The relative yields from single- or multiple-row plats with either 18- or 24-inch row-spacing likewise exhibited no rignificant differential interaction and compared favorably with the yields from field plats. There were, however, some indications of interplat competition between single rows spaced 18 inches apart and one might expect this to be a possible source of error. Space-planted nurseries would seem to be less accurate for yield determinations than solid-drilled rows for testing alfalfa strains, especially if they differ in rate of crown development.

Rate-of-seeding tests in connection with multiple-row nursery plats in which the rows were spaced 18 and 24 inches apart indicate that there may be considerable latitude in the amount of seed sown, within reasonable limits, without significantly affecting the comparative varietal performance. When the seed was sown in equal amounts (15 pounds) per acre in rows spaced 7, 18, and 24 inches apart, the 18- and 24-inch rows yielded from 5 to 11% less than when the rate of seeding per row was the same as in the 7-inch rows. As the distance between nursery rows is increased much beyond 7 inches, it seems preferable to hold constant the amount of seed sown per row rather than the amount sown per acre. Plant mortality was far greater in the heavily-seeded rows and stands tended to equalize after 4 years.

Yields from nursery plats were analyzed statistically to study the effect of area of land on variability. Using the same yields and total area in the two comparisons, the yield variability for the entire nursery was significantly greater than when the replicates were restricted to any fourth of its area.

Comparison of adjacent unlike plat types showed striking and significant modifications in plat yields. For example, when a solid-

planted row was 7 inches from a space-planted row it gave an excess yield of 74%, while the space-planted row was depressed 63% in yield. Similar results were obtained when unequal adjacent spacings were involved. It seems evident that great care must be exercised in taking yields from adjacent rows which are apt to be either at an advantage or disadvantage with respect to spacing of rows or density of stand.

The number of replications required to make a 5% difference statistically significant has been calculated and found to vary from 4 to 16 for the different types of plats under these conditions.

Based on the specific principles indicated by these studies and also on general experience with alfalfa nurseries, the most serviceable types of plat for advanced nursery testing appear to be somewhat optional among the following: (1) Solid-drilled 5 to 8 rows spaced 7 inches apart, with a 12- to 14-inch alley between border rows; or (2) solid-drilled 3 to 5 rows spaced 12 inches apart with an 18-inch alley between border rows. Since removing border rows is difficult and expensive with this crop and since very little error has been found with such plats due to border effect, it is suggested that the entire plat may be harvested for yield, with the possible exception of removing border rows in case adjacent stands are decidedly different. This would also facilitate machine harvesting. The plats may be 16 feet or more in length, depending on circumstances, and the alley space should be included in the plat area. Single rows spaced 18 to 24 inches apart are permissible for preliminary nursery testing.

PHOSPHORUS FIXATION BY HORIZONS OF VARIOUS SOIL TYPES IN RELATION TO DILUTE ACID EXTRACTABLE IRON AND ALUMINUM[1]

DALE S. ROMINE AND W. H. METZGER[2]

IN a study of relative phosphorus fixation by several horizons of each of a number of soil types, interest centered in a possible relationship between the dilute acid extractable iron and aluminum and the phosphorus-fixing capacity of the various horizons. The relationship was studied by determining phosphorus absorption by the soil in its original condition and again determining absorption after the available phosphorus had been extracted by the method of Truog (8).[3] Truog's method of extraction was used because it involves the use of a very dilute acid and it removes the "available" phosphorus from the soil fairly accurately. The acid can remove only small amounts of iron and aluminum because of the degree of dilution, but it was believed that this dilute acid extractable iron and aluminum might be closely related to the ability of the soil to take up phosphorus from solution.

It is generally recognized that phosphorus availability not only varies with the different forms in which phosphorus is fixed in the soil, but apparently there are varying degrees of availability within the same form.

Truog (9) has shown that at least a portion of the phosphorus in precipitated ferric and aluminum phosphates is available to plants. Heck (4) states that when active calcium and aluminum are low, phosphates are fixed largely by iron and the resulting compound is generally less soluble than the corresponding aluminum compound.

Ford (2) reports that hematite did not appear to fix phosphates, whereas goethite fixed large amounts. McGeorge and Breazeale (6) observed that iron and aluminum hydrogels fixed large amounts of phosphorus which was insoluble in water but completely soluble in dilute HCl. Meyer (7) believes an iron compound to be responsible for the fixation of phosphorus in soils of the South. It occurs in concretions and fixes phosphorus as a basic ferrous phosphate. Heck (5) found that dark-colored soils containing abundant organic matter were generally low-fixing soils. Reddish yellow or yellow soils have the highest fixing power. This color arises from the presence of monohydrate (and perhaps dihydrate) ferric oxide, which is highly reactive. Truog and Ford (10) state that yellow-colored soils fix phosphorus more readily than do red-colored soils because of a difference in the form of iron compounds in these soils. Hance (3) states that subsoils show higher fixing power than surface soils. He defines a high-fixing soil as one that allows the soluble phosphates to penetrate 2 or 3 inches and a mild-fixing soil as one that allows penetration to a depth of 2 or 3 feet.

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[1]Contribution number 284 from the Department of Agronomy, Kansas State College, Manhattan, Kans. Part of a thesis submitted to the Graduate School of Kansas State College by the senior author in partial fulfillment of the requirements for the degree of master of science.

[2]Graduate student and Associate Professor of Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 107.

SOIL PROFILES STUDIED

Since leached soils are comparatively high fixers of phosphorus, it was deemed advisable to confine this study primarily to relatively heavily leached soils. Representative profiles studied are briefly described below.

The Cherokee silt loam is a heavily leached prairie soil developed in the more nearly level areas of eastern Kansas. The lack of relief, together with the heavy claypan subsoil, renders drainage poor. The Labette silt loam is residual from gypsiferous shales and limestone. The lower part of the surface soil contains numerous iron concretions. The lower part of the subsoil is high in iron.

The Knox silt loam is an open, friable soil which has developed from loessial material. The profile studied was taken from very hilly topography. The Marshall silt loam is a dark-colored upland soil with a friable subsoil. The profile has developed from loessial deposits. The Derby silt loam is a friable, moderately leached soil of wind-blown origin.

The Summit silt loam has developed from the weathering of limestone and shale. Dark brown to black iron concretions and stains are numerous in the lower subsoil. The general topography of the region in which this soil occurs is undulating to gently rolling or rolling. The Shelby silt loam is derived from glacial till. The subsoil contains numerous iron concretions. The Idana silt loam is derived from calcareous shales and limestones. A few of the more nearly level areas are underlain by a somewhat heavy subsoil, approaching a claypan.

The Hays silt loam has developed on residual material from limestone. A lime zone is encountered in the subsoil, usually below 30 inches depth, but much shallower on slopes.

All of the above soils, except the Hays, lie in the prairie soils area in Kansas, and have developed under an average annual precipitation ranging from 30 to 40 inches. The Hays profile has developed under approximately 22 inches of average annual rainfall, and lies in the Chernozem belt.

ANALYTICAL METHODS

To determine the absorption of phosphorus by the original soil, 10-gram samples of 100-mesh soil from each horizontal subdivision were placed in a 200-ml. shaker bottle with 50 ml. of dilute phosphoric acid solution containing a known quantity of phosphorus. They were then placed on a shaker, agitated for 30 minutes, and filtered. The phosphorus concentration of the filtrate was determined by the Truog (8) method. It was assumed that the decrease in phosphorus content of the solution represented phosphorus fixed by the soil. No attempt was made to distinguish between fixation in easily soluble and in difficultly soluble form. In order to prevent an extreme variation in the phosphorus concentration of the filtrate, standardized phosphoric acid solutions of four different concentrations were used, *viz.*, 19 p.p.m., 38 p.p.m., 57 p.p.m., and 95 p.p.m. of elemental phosphorus, the strength used for each sample being determined by the amount of phosphorus the soil would absorb. The pH value ranged from 2.7 for the solution containing 95 p.p.m. to 3.1 for that containing 19 p.p.m.

Truog's buffered extracting solution has a pH value of 3.0. The soil-solution ratio used was 1:200 and the time of shaking was 30 minutes. Since the pH values of the phosphorus solutions used in the absorption studies were so nearly the same as that of the Truog solution, it was assumed that absorption as determined for the original soil should be comparable to that for extracted soil except for

changes induced by the extraction of the soil with the Truog solution. The pH values at which absorption took place were not measured but under these conditions must have been similar for the original soil and the extracted soil. The soil-solution ratios and the time of contact between soil and solution, as well as the manner of shaking, were kept constant throughout.

To determine the absorption after extraction of "available" phosphorus, the soil and extract from the Truog procedure were separated by centrifuging. This means of separation made possible the obtaining of the soil needed for the absorption determination with negligible mechanical loss. To the extracted soil thus obtained was added standard phosphoric acid solution of the same concentration as was added to the corresponding sample in the original absorption determination. The remaining procedure was identical with that used for the original determination.

The supernatant liquid obtained after centrifuging was divided into two aliquots. One was used to determine the "available" phosphorus according to Truog's procedure. To the other was added dilute NH_4OH to precipitate iron and aluminum and other substances precipitated by this reagent. The precipitate was separated by filtration, ignited, and determined as R_2O_3. All of the NH_4OH precipitates are expressed as R_2O_3 in Table 1. This appeared justifiable since the amount of phosphorus precipitated was negligible in comparison with the amount of sesquioxides.

The pH value of the soils was determined with the quinhydrone electrode, using a 1:1 soil-water ratio.

EXPERIMENTAL RESULTS

On account of the desirability of making comparisons of the data for one profile with those for another and also the importance of comparing the data for the various horizons within each profile, it appeared logical to group all of the data in a body. All data obtained therefore are presented in Table 1.

PHOSPHORUS ABSORPTION BY THE ORIGINAL SOIL

In all soils studied, the B horizon showed greater absorption than the A horizon. This was more pronounced in the more severely leached soils than in those less affected by leaching. The explanation for this probably lies in the fact that the B horizon is the zone of accumulation of iron and aluminum leached from the A horizon. It is recognized that the pH values at which absorption took place with samples from the various horizons were probably somewhat variable. However, the pH values of the B horizons were in most cases quite similar to those for the lower portion of the A horizons. Also, since the soil-solution ratio during absorption was 1:5 and therefore differences in the buffering effect of the soil samples on an acid with the buffering properties of H_3PO_4 were probably small, it appears that the influence of accumulated iron and aluminum in the B horizons is the most likely explanation for their high absorption values as compared to the A horizons.

A striking example of the indirect influence of leaching on phosphorus absorption was revealed in comparing the original absorption of the Knox profile with that of the Hays profile. It was found that

TABLE 1.—*Phosphorus absorption of various soils as related to dilute acid extractable R_2O_3, pH value, and soil type.*

Horizon and depth, in.	Phosphorus absorbed by original soil, p.p.m.*	Available phosphorus, p.p.m.	Apparent absorptive capacity, p.p.m.†	Phosphorus absorbed after extraction, p.p.m.	Reduction of absorptive capacity, p.p.m.	Reduction in absorptive capacity, %	R_2O_3 removed by extraction reagent (mgm per 100 grams of soil), mgm.	pH value
Cherokee Silt Loam (Labette County)								
A 0–4	47.5	14.6	62.1	20.0	42.1	67.8	50	5.91
A 4–12	65.0	4.5	69.5	27.0	42.5	61.2	40	5.26
A 12–18	80.6	4.0	84.6	32.5	52.1	61.6	50	4.97
A 18–20	88.4	4.0	92.4	55.0	37.4	40.5	57	4.98
B 20–23	179.4	4.0	183.4	97.5	85.9	46.9	120	5.12
B 23–28	176.5	4.0	180.5	95.5	85.0	47.0	130	5.51
C 34+	87.1	18.5	91.1	57.0	34.1	37.5	87	6.42
Labette Silt Loam (Allen County)								
A 0–2	71.2	19.0	90.2	40.0	50.2	55.6	35	5.58
A 2–14	83.7	7.5	91.2	45.0	46.2	50.5	45	4.86
B 14–24	180.5	5.0	185.5	135.0	50.5	27.0	87	4.84
C 24+	454.6	4.0	458.6	375.0	83.6	18.1	112	4.90
Knox Silt Loam (Doniphan County)								
A 0–8	72.2	38.0	110.5	25.0	85.5	77.4	45	7.32
B 8–24	75.0	60.0	135.0	23.5	111.5	82.6	62	6.65
C 24+	78.7	100.0	178.7	21.7	157.0	87.8	87	7.19
Marshall Silt Loam (Doniphan-Brown County Line)								
A 0–4	56.2	80.0	136.2	18.0	118.2	86.8	85	6.28
A 4–14	69.6	32.0	101.6	27.5	74.1	73.0	57	6.72
B 14–30	88.6	14.0	102.6	50.0	52.6	51.0	75	6.04
C 30+	84.2	45.0	129.2	45.0	84.2	65.2	120	6.04

			Derby Silt Loam (Clay County)					
A 0–3	46.2	24.0	70.2	25.0	45.2	64.4	22	6.59
A 3–9	69.9	25.0	94.0	40.0	54.0	57.5	40	5.60
A 9–17	146.2	12.5	158.7	75.0	83.5	52.5	50	5.55
B 17–27	160.0	13.6	173.6	75.0	98.6	56.8	60	5.65
C 27+	80.9	51.2	132.2	40.0	92.2	69.5	45	6.84
			Summit Silt Loam (Allen County)					
A 0–2	58.2	24.0	82.2	35.0	47.2	57.5	30	5.64
A 2–13	85.0	4.0	89.0	45.0	44.0	49.4	45	5.59
B 13–28	432.0	4.5	438.5	332.5	106.0	24.2	102	5.58
C 28+	411.0	10.0	421.0	320.0	101.0	24.0	95	6.82
			Shelby Silt Loam (Leavenworth County)					
A 0–4	76.5	17.0	93.5	15.0	78.5	84.0	60	5.52
A 4–7	80.9	12.5	93.4	15.0	78.4	84.0	67	5.42
B 7–20	358.8	6.5	364.5	225.0	139.5	38.2	127	5.52
C 20+	347.9	42.0	389.9	255.0	134.9	34.6	117	6.18
			Idana Silt Loam (Clay County)					
A 0–5	60.0	26.6	86.6	15.0	71.6	82.6	30	6.13
A 5–15	63.7	13.5	77.2	15.0	62.2	80.5	42	5.91
A 15–19	70.8	14.5	85.3	22.5	62.8	73.6	50	5.59
B 19–29	87.8	32.0	119.8	61.7	58.1	48.5	62	6.75
C 29+	80.8	33.3	104.1	55.0	59.0	56.7	50	7.84
			Hays Silt Loam (Smith County)					
1 0–12	78.1	52.0	130.1	10.0	120.1	92.3	60	6.45
2 12–30	81.5	60.0	141.5	15.0	126.5	89.4	67	6.84
3 30–38	75.0	62.5	137.5	10.0	127.5	92.7	87	7.49

*Parts per million parts of air-dry soil.
†Apparent absorptive capacity = available phosphorus plus phosphorus absorbed by original soil and is therefore an arbitrary value applicable only to the methods employed in this work.

original absorption values throughout the two profiles were nearly equal. The Knox profile has developed in a region having an average annual rainfall of about 35 inches, while the Hays profile has developed under approximately 22 inches of annual precipitation. Equal absorption by the two profiles, therefore, appears inconsistent with other findings in this study, namely, that the profiles which had developed under the heaviest rainfall exhibited the highest absorption. When it is considered that the Knox profile studied was developed on a very hilly topography, equality in absorption by the two profiles can be explained. Because of a hilly topography and consequently a greater run-off and more erosion, leaching has not been as extensive and therefore less effective in developing a zone of iron and aluminum accumulation than would be true with equal rainfall on more level areas in the same environment. The hilly topography has apparently offset the difference of 13 inches in rainfall so that the Knox and the Hays profiles are comparable in that neither has developed a marked zone of iron and aluminum accumulation. This is further evidenced by their comparable pH values.

"AVAILABLE" PHOSPHORUS IN THE ORIGINAL SOILS

In all horizons low availability was associated with low pH values as revealed in Fig. 1. This is probably due to the lack of strong bases

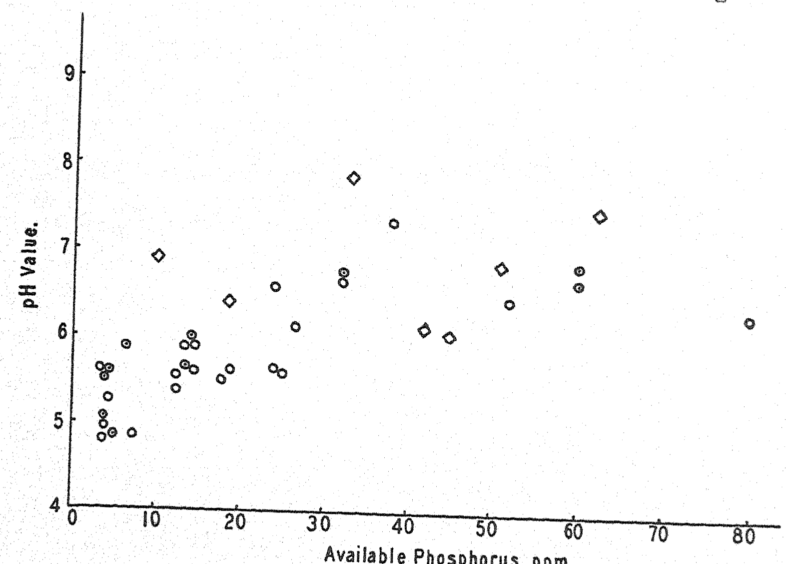

FIG. 1.—Available phosphorus in relation to pH value. Circle = A horizon; Circle with dot = B horizon; Diamond = C horizon.

indicated by low pH values and a consequent increase in the activity of iron and aluminum in phosphorus fixation.

In the more severely leached soils low availability extended throughout the lower part of the profile, while in the relatively un-

leached soils "available" phosphorus tended to increase with depth, reaching a maximum in the C horizon.

No well-defined relationship appeared to exist between the R_2O_3 extracted by the Truog extracting solution and the available phosphorus of the various horizons. However, in the relatively unleached profiles (Hays, Knox), it was found that comparatively high "available" phosphorus was associated with a relatively high amount of dilute acid extractable R_2O_3 in all horizons.

Generally speaking, lowest availability occurred in the B horizons. This is in agreement with the well known and widely recognized low availability of phosphorus in subsoils as indicated by plant growth. Since B horizons show high absorptive capacity and low availability of phosphorus, there is suggested the idea of using the absorptive capacity of the soil rather than the amount of "available" phosphorus extracted as a measure of the soil's need for phosphorus.

PHOSPHORUS ABSORBED AFTER EXTRACTION OF SOIL WITH TRUOG'S REAGENT

In all cases the extraction of "available" phosphorus reduced the capacity of the soil to absorb phosphorus as shown in Table 1. The percentage reduction was highest in the soils which had been subjected to least leaching. In all of the soils studied the percentage reduction in the A horizon was greater than either the B or C horizons.

The B and C horizons of the Shelby, Summit, and Labette profiles exhibited comparatively high absorption after extraction, as shown in Table 1. It is of interest, however, to note that the reduction in absorptive capacity in these horizons compared rather favorably with other findings in this study, namely, that there is a general relationship between the R_2O_3 extracted and the reduction in "apparent absorptive capacity"—available phosphorus plus original absorption. The relation between R_2O_3 extracted and the reduction in "apparent absorptive capacity" is indicated in Fig. 2. These data suggest the possibility that plants grown on leached soils are dependent for available phosphorus largely upon phosphorus combined with the sesquioxide constituents.

SESQUIOXIDES EXTRACTED BY TRUOG'S REAGENT

Under the conditions established, it was believed that by adding the available phosphorus to that absorbed by the original soil, a measure of its absorptive capacity would be obtained. The values so obtained were designated "apparent absorptive capacity." These values were plotted against the R_2O_3 extracted and a scatter diagram is shown in Fig. 3. The five isolated points at the right hand side of the figure represent values for both the B and C horizons of the Summit and Shelby profiles and the C horizon of the Labette profile. It is apparent that the relatively high absorption in these horizons is due in part to factors other than extractable sesquioxides. One of the authors has shown that the B and C horizons of these profiles contain from 50 to 65% of particles of colloidal size. This very high content of colloids may offer an explanation of the behavior of these

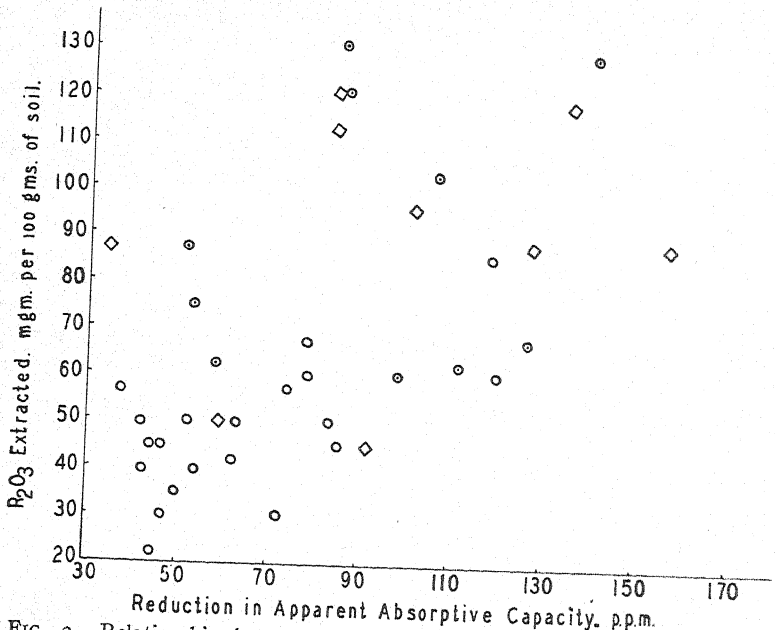

FIG. 2.—Relationship between R_2O_3 extracted and reduction in apparent absorptive capacity. Circle = A Horizon; Circle with dot = B Horizon; Diamond = C Horizon.

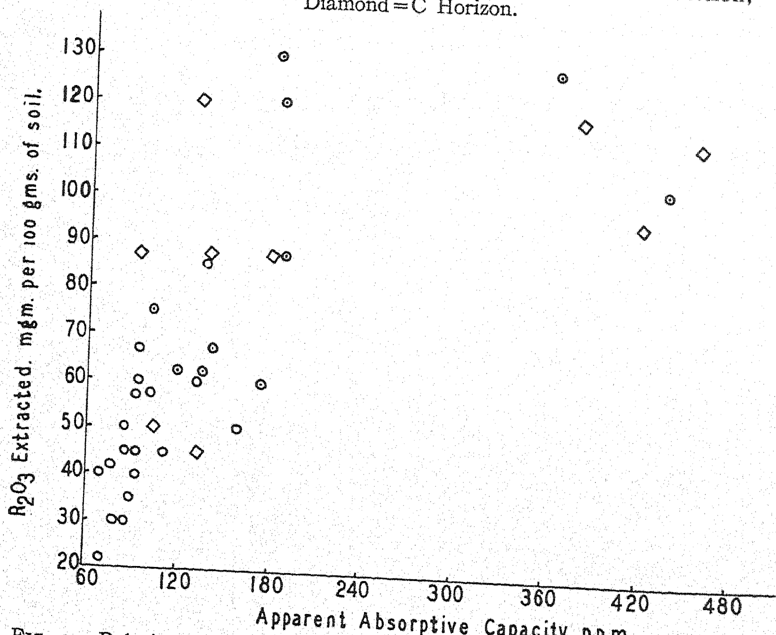

FIG. 3.—Relation between R_2O_3 extracted and apparent absorptive capacity. Circle = A Horizon; Circle with dot = B Horizon; Diamond = C horizon.

profiles due to surface absorption of phosphorus as proposed by Bradfield, Scarseth and Steele (1). It may also be true that the extracting solution, which was 0.002 N with respect to H_2SO_4 and contained 3 grams of $(NH_4)_2SO_4$ per liter, was too weak to remove more than a very small portion of the abundant free iron from these horizons. Hence, the absorption after extraction might be greater in proportion to the original absorption than in soils in which a larger portion of the free iron was removed by the extracting reagent.

Data presented in Table 1 reveal that B horizons of the relatively leached soils are generally deficient in "available" phosphorus and that low availability is usually associated with a high absorptive capacity. Therefore, from a practical point of view, not only is the amount of "available" phosphorus important, but also the degree to which the constituents capable of absorbing phosphorus are saturated by this element.

SUMMARY

Relative phosphorus-fixing capacity of several horizons of each of a number of soil types has been studied and an attempt made to determine the possible relationship between the dilute acid extractable R_2O_3 and the phosphorus-fixing capacity of the various horizons.

Extraction of "available" phosphorus by Truog's solution reduced the capacity of the soil to absorb phosphorus. The percentage reduction in absorption after extraction of "available" phosphorus was highest in the relatively unleached soils. The percentage reduction in the A horizons was greater than in either the B or C horizons.

In all horizons the reduction in "apparent absorptive capacity" (available phosphorus plus phosphorus absorbed by original soil) resulting from extraction of the soil by the Truog reagent varied with the general trend of the R_2O_3 extracted.

The B and C horizons of rather heavily leached soils absorbed from 2 to 5 times as much phosphorus as did the B and C horizons of the relatively unleached soils. In all cases the B horizons showed greater absorption than the A horizons.

Generally speaking, lowest availability occurred in the B horizons. In the unleached profiles, high "available" phosphorus was associated with relatively high amounts of extractable R_2O_3. Low availability was associated with low pH values.

LITERATURE CITED

1. Bradfield, Richard, Scarseth, George, and Steele, J. G. Factors affecting the retention of phosphate by clays. Trans. Third Int. Cong. Soil Sci., 1:74–75. 1935.
2. Ford, M. C. The nature of phosphate fixation in soils. Jour. Amer. Soc. Agron., 25:134–144. 1933.
3. Hance, F. E. Phosphate fixation in Hawaiian soils. Hawaii Planters' Rec., 37:182–196. 1933.
4. Heck, A. F. Phosphate fixation and penetration in soils. Soil Science, 37:343–355. 1934.
5. ———. Availability and fixation of phosphorus in Hawaiian soils. Jour. Amer. Soc. Agron., 27:874–884. 1935.

6. McGeorge, W. T., and Breazeale, J. F. Studies on iron, aluminum and organic phosphates and phosphate fixation in calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 40. 1932.
7. Meyer, A. H. Phosphate fixing compounds in the soil. Soil Science, 71:457. 1930.
8. Truog, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:873–882. 1930.
9. ————. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.
10. ———— and Ford, M. C. New science for an old art. Wis. Agr. Exp. Sta. Bul. 410:6–8. 1930.

STORAGE OF SUGAR BEETS UNDER CONDITIONS OF HIGH HUMIDITY AND LOW TEMPERATURE[1]

John O. Gaskill and H. E. Brewbaker[2]

STORAGE of sugar beets for breeding purposes has been accomplished in the past in a number of ways. The methods most commonly employed included the root storage cellar and the pit silo or trench, in each of which the beets as a rule were covered by or packed in some moisture-holding medium, such as moist sand, as recommended by Pack (3),[3] or ordinary moist field soil. Straw cover has been used to some extent, and Harris (1) reported satisfactory results from storage in dry sand. Kohls (2) reported that mother beets coated with paraffin and stored in crates in a root cellar, without sand or any other covering or packing material, kept satisfactorily. For best results it was necessary to remove the paraffin from the root sutures before planting. The importance of minimizing loss of water from the roots apparently has been rather generally recognized, and was emphasized by Pack.

For the period between harvest and analysis, Pack (4) suggested piling without packing material in a ventilated but covered pit in order to induce a more uniform moisture content. He recommended that the roots be analyzed within a relatively short period after harvest and then be stored over winter in moist sand.

This paper describes a method of moist cellar storage in which considerable economy of labor is effected through elimination of paraffin, sand, or other treatment. The loss of sucrose which occurred in beets stored by this method is compared with that which occurred with the ordinary pit silo.

METHODS

Several crates of mother beets were stored satisfactorily throughout the entire winter of 1933–34 in a root cellar at the U. S. Sugar Plant Field Station, Fort Collins, Colo, without the use of paraffin coating, packing material, or cover of any kind. These roots, after about 2 months of storage, were rasped as though for analysis and then returned to the cellar, simulating approximately the usual routine of handling mother beets at the station. Temperatures a few degrees above the freezing point and high humidity were maintained. No loss in weight occurred, other than that resulting directly from the removal of a portion of each root in the rasping operation, foliage growth was slight, and the beets were in good condition at the end of the storage period.

In the fall of 1934, this method of storage was adopted for general use at the station. Satisfactory results were obtained during the two winters which followed,

[1]Contribution from the Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Colorado Agricultural Experiment Station, Fort Collins, Colo. Received for publication November 17, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 115.

and in 1936 a reinforced concrete cellar (Figs. 1 and 2), 12 feet wide and 32 feet long, was constructed which was designed to permit control of temperature and humidity without the use of refrigerating apparatus. In general, the procedure employed for sugar beet storage with this cellar is as follows: Beets are washed, numbered with indelible pencil, and placed in crates which are so arranged as to facilitate circulation of air. For a short time during the early fall, cakes of ice are placed in the center aisle, and air is circulated within the room, passing from the fan directly over the ice. Later, when nights are cooler, the use of ice is discontinued, outside air is drawn into the cellar at night, the ventilators being kept closed during the day. While in operation for cooling purposes, the fan is thermostatically controlled, being shut off as temperature in the cellar approaches the freezing point. Throughout the remainder of the storage period, it is used continuously for circulation of air within the room. High humidity is maintained throughout most of the storage season by means of two overhead nozzles which operate under city water pressure and produce a misty spray. During the early fall, supplemental moisture is provided by daily sprinkling of crates and cellar

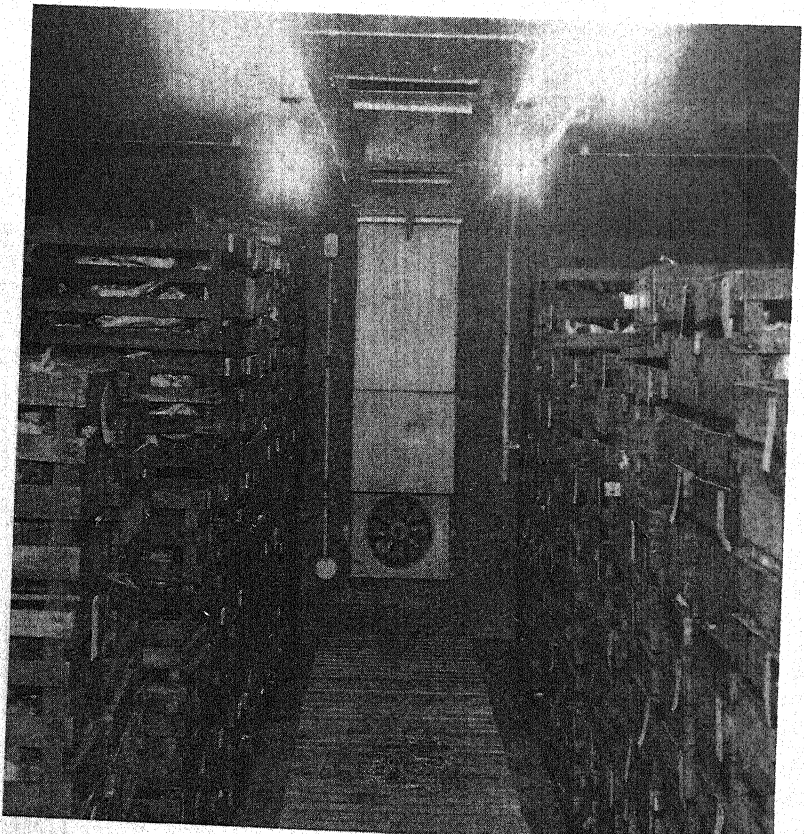

FIG. 1.—Interior view of root storage cellar, Fort Collins, Colo., showing overhead conduit and thermostatically controlled, 12-inch ventilating fan which serve both for intake of air and for circulation.

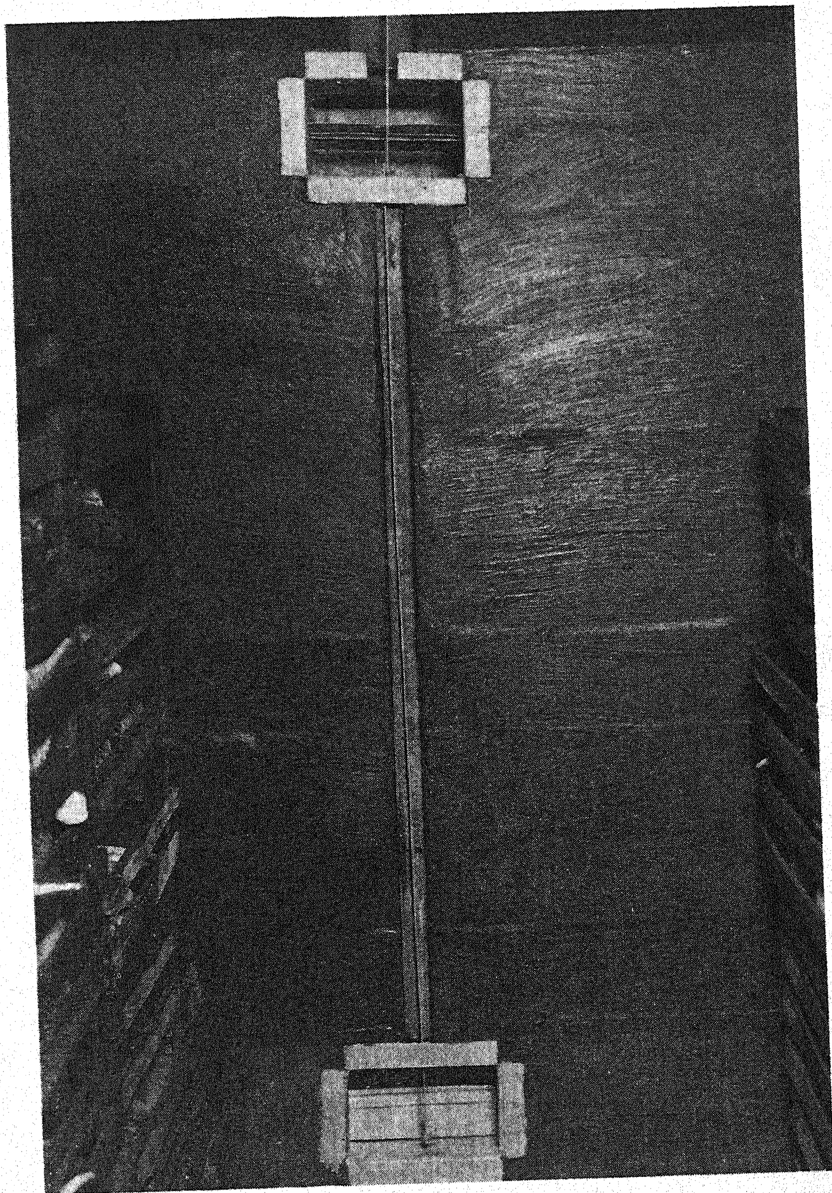

FIG. 2.—Interior view of one of the four pairs of exhaust vents in root storage cellar. The shutters are controlled manually from the center aisle (note overhead levers near the rear in Fig. 1) and may be used to liberate air from either the top or bottom of the room.

walls, plus thorough drenching of the beets one or twice each week. Drainage is provided by means of a pit located under the slatted aisle floor.

The feasibility of storing mother beets by such methods having been demonstrated, a test was conducted during the winter of 1936–37 to compare this type of storage with pitting in the field.

EXPERIMENTAL

In the latter part of October 1936, approximately 650 sugar beet roots of a commercial variety were washed and trimmed in the usual manner for mother beets and placed in crates in the cellar. On November 23, these roots were divided by a random method into five identical lots, numbered from 1 to 5. Each root in lot 1 was weighed and analyzed for sucrose percentage immediately, using the boring method recommended by Sherwood (5) for individual beets. Lots 2, 3, and 4 were stored in crates in the cellar for periods of 41, 84, and 125 days, respectively, and lot 5 was stored in an ordinary outdoor silo for 125 days. The silo conformed to the usual type employed commercially in northern Colorado, consisting of a trench 1 foot deep and 6 feet wide, in which the beets were piled and covered with moist soil to a depth of approximately 3 feet. All roots in lots 2, 3, 4, and 5 were weighed and analyzed immediately after removal from storage. The procedure of analyzing each beet before and after storage, as followed by various investigators, was not used in this experiment since study of the rate of loss of sucrose in normal, uninjured beets was the principal object of the test.

Temperature and relative humidity were recorded continuously in the cellar during the period of the experiment by means of a hygrothermograph. Actual temperature in the silo was not recorded, but records provided by the Colorado Agricultural Experiment Station served to indicate approximate outdoor temperature conditions existing throughout the duration of the experiment. Mean weekly temperature and relative humidity data are shown in Fig. 3. The average cellar temperature during the 125-day period was 35.9° F and relative humidity averaged 96.5%. The mean outdoor air temperature was 26.8° F.

The summarized data for weight and sucrose are presented in Table 1 and Fig. 4. None of the differences between lots, in average weight per root, was significant, as indicated by the negative "z" value and the relatively large difference required for significance. The gradual but significant decline in sucrose percentage which occurred in roots stored under cellar conditions was accompanied by an approximately equivalent loss in the silo, as indicated by the means for lots 4 and 5. Because of the direct effect of weight changes, however slight, upon sucrose percentage, the actual weight of sucrose per root, or sucrose content, is a more accurate measure of gain or loss in this respect. These data show a loss in sucrose, in both silo and cellar, which followed the same general trend as with the percentage figures, but experimental error was relatively greater, and the total loss of sucrose in 125 days of storage was not significant, indicating that 130 beets per lot were not sufficient to measure adequately the small decline in sucrose content which occurred under the conditions of this experiment.

TABLE 1.—*Loss of sucrose from sugar beets under moist cellar and under pit silo conditions, Fort Collins, Colo., Nov. 24, 1936, to March 29, 1937.*

Lot No.	Method of storage	Date of analysis	Length of storage, days	Av. wt. per root, lbs.	Av. sucrose, %	Av. sucrose, per root, lbs.	% loss in weight of sucrose per root: Total	Per day
1	.....	Nov. 24, '36	0	1.452	15.74	0.2280	...	...
2	Cellar	Jan. 4, '37	41	1.416	15.53	0.2194	3.77	0.09
3	Cellar	Feb 16, '37	84	1.491	15.09	0.2247	1.45	0.02
4	Cellar	Mar. 29, '37	125	1.460	14.77	0.2158	5.35	0.04
5	Pit silo	Mar. 29, '37	125	1.477	14.68	0.2171	4.78	0.04

z	−0.1114	1.3359	0.0280
5% point	>0.8639	<0.4632	>0.4319
1% point	>1.3000	<0.6472	>0.5999
S.E. of mean	0.0319	0.121	0.00505
Diff. for significance (odds approx. 19:1)	0.090	0.34	0.0143

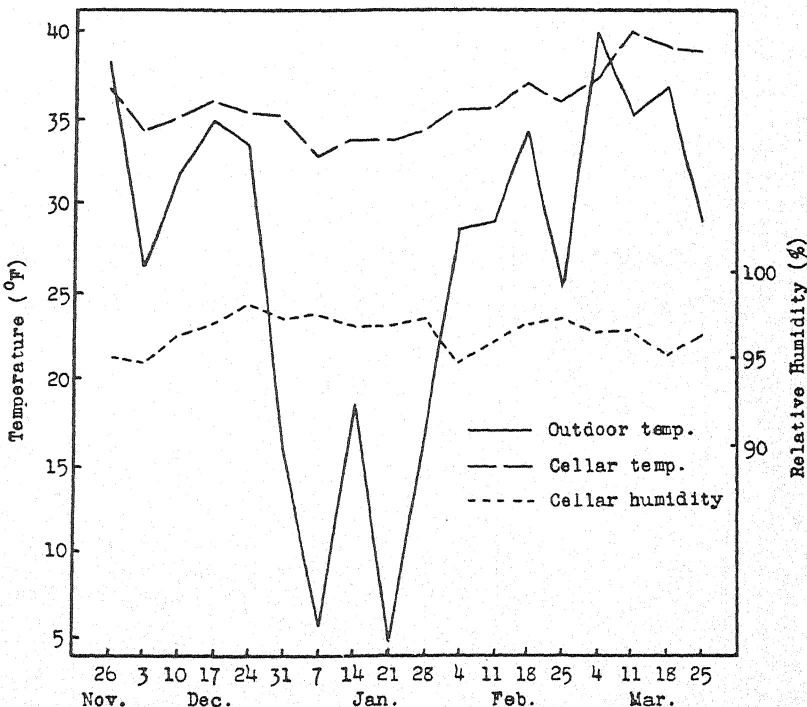

FIG. 3.—Mean weekly outdoor temperature and temperature and relative humidity in cellar, Fort Collins, Colo., 1936–37.

Recognizing this fact, definite conclusions cannot be reached regarding comparative rates of sucrose loss in cellar and silo. The data suggest, however, that the two methods of storage were approximately

equal when compared on the basis of preservation of sucrose. As shown in Table 1, the loss of sucrose in both cellar and silo averaged 0.04% per day, which, because of negligible change in weight and absence of rot, may be attributed largely to respiration, on the assumption that the proportion of the sucrose loss which could be accounted for by an increase in reducing sugars was relatively slight,

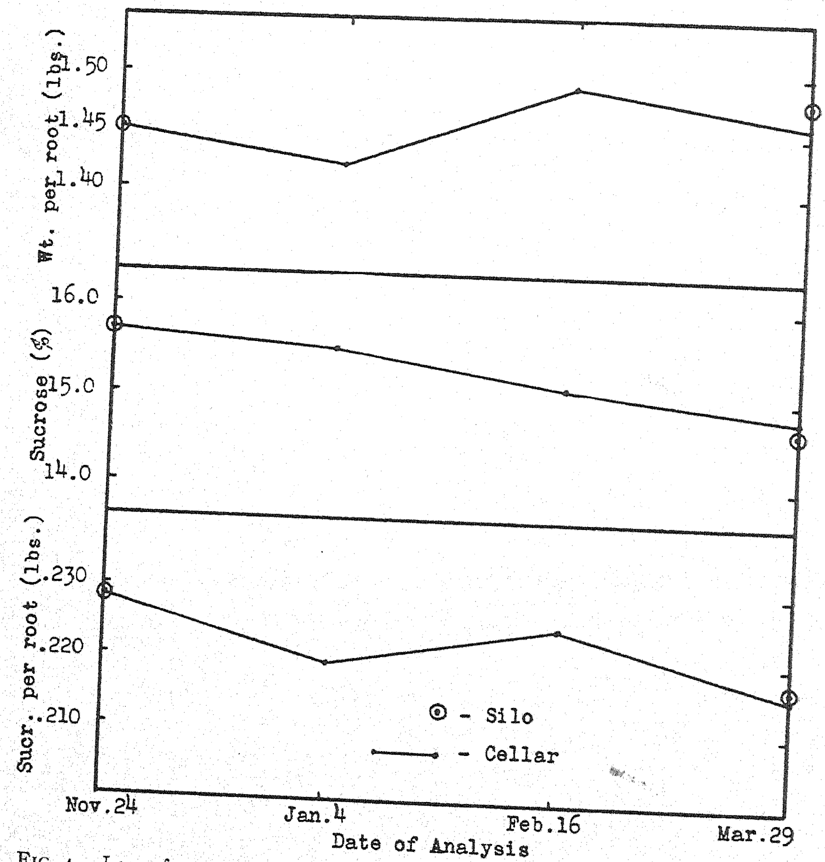

FIG. 4.—Loss of sucrose from sugar beets under moist cellar and under pit silo conditions, Fort Collins, Colo., 1936–37.

as was indicated by data presented by Pack (3). It is of interest in this connection that Pack reported a loss of sucrose which amounted to 0.12% per day in beets which were stored in moist sand for 98 days at a temperature of 1.7° C—approximately equal to the average temperature recorded in the Fort Collins cellar during the 125-day storage period. The larger rate of loss reported by Pack may be accounted for, at least in part, by the fact that the roots in his experiment were analyzed before as well as after storage, while those in the Fort Collins test remained uninjured until the end of storage.

Rotting of roots was not a factor in this storage test irrespective of whether cellar or pit-silo was used. However, serious losses of stored roots through fungus attack, freezing, or suffocation have not been infrequent with sugar beets kept in pits or packed in moist sand in the ordinary root cellar. Among the causes of loss of roots, fungus decay has been important. Starting with a few individuals, rotting shortly involves surrounding roots. The increase in temperature within a covered storage pile, which is brought about by the respiration of the decay-producing organisms, accelerates fungus activity so that the spread of rotting is rapid and serious loss may occur within a short time. In the five years' experience with storage in open crates with temperature and humidity controlled as described, only negligible losses from rotting have occurred.

SUMMARY

During five winter storage periods, sugar beet roots being saved for seed production have been kept with negligible loss from rotting in open crates, without any coating or packing material, by maintaining the temperature of the root cellar a few degrees above freezing, the humidity near saturation, and by providing for thorough air circulation.

It was found by test that sugar beets stored 0, 41, 84, and 125 days in the cellar, or 125 days in an outdoor pit-silo, did not differ significantly in root weight. Gradual but statistically significant decline in sucrose percentage occurred with the longer storage periods. Under the conditions, sucrose loss averaged 0.04% per day, attributed largely to respiration. Comparison of cellar-stored and pit-siloed roots after 125 days storage indicated equivalent behavior.

The cellar storage method as described is convenient and efficient for storing small lots of sugar beet breeding strains.

LITERATURE CITED

1. HARRIS, FRANK S. The commercial production of sugar beet seed in Utah. Utah Agr. Col. Exp. Sta. Bul. 136. 1915.
2. KOHLS, H. L. Use of paraffin for overwinter storage of sugar beets. Jour. Amer. Soc. Agron., 26:846–851. 1934.
3. PACK, D. A. The storage of sugar beets. Facts About Sugar, 19:178–180; 208–209; 232–235; and 251–253. 1924.
4. ————. The storage of mother beets. Facts About Sugar, 20:874–875. 1925.
5. SHERWOOD, S. F. Sucrose in seed beets. Sugar, 23:299–300. 1921.

DETERMINATION OF THE WEIGHT OF WATER IN A SOIL OR SUBSOIL MASS IN WHICH THE MOISTURE CONTENT INCREASES WITH DISTANCE FROM A PLANT OR GROUP OF PLANTS[1]

M. L. JACKSON AND M. D. WELDON[2]

IN a soil mass in which the moisture content is uniform, the computation of weight of water is relatively simple. A more involved process is required for the computation, however, when the water content varies with distance from a plant. Such distribution is encountered in subsoil moisture studies in orchards (4, 5)[3] and possibly in lysimeter and other moisture studies. The purpose of this paper is to present formulas suitable for calculating the weight of water in soil and substrata in which the moisture content is not uniform but varies systematically.[4] The formulas are applicable to fields in which plants or hills are regularly spaced, and several possible spacings are considered.

Ordinary arithmetical operations suffice in applying the formulas, although higher mathematics[5] is required in their derivations. Attempt has been made to explain the logic of the derivations in such a way as to facilitate their modification and re-arrangement to fit the individual needs of the user. Suggestions are made where further development may be desirable.

INCREASE IN MOISTURE CONTENT WITH DISTANCE FROM PLANT

The simplest case is that in which, first, the angular rotation about the plant does not affect the moisture content, that is, points at equal distances from the plant have equal moisture contents, and second, the increase in moisture percentage is proportional to the distance from the plant. The general equation which expresses these relationships is the equation for a straight line:

$$y = mx + b \tag{1}$$

in which y is the amount of water (pounds per cubic foot of soil), x is the distance from the plant in feet, and m and b are constants to be evaluated from data obtained in the field. The field data in Table 1 will now be used to illustrate the calculation of m and b.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Approved as Nebr. Agr. Exp. Station Paper No. 221 Journal Series. Received for publication November 17, 1938.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 127.

[4]The authors are indebted to C. C. Wiggans, Department of Horticulture, University of Nebraska, for some illustrative data used in this paper.

[5]Acknowledgments for checking the mathematics involved, are made to Dr. C. Eisenhart, Instructor in Mathematics, University of Wisconsin, and Station Statistician, Wisconsin Agr. Exp. Sta., Madison, Wis., and to Miss Zoe F. Schnabel, University Computer, Department of Mathematics, University of Wisconsin.

TABLE 1.—*Field moisture data illustrating increasing moisture content with distance from plant.*

		A (x_1, y_1)	B (x_2, y_2)	C (x_3, y_3)
Points on graph (Fig. 1)		A (x_1, y_1)	B (x_2, y_2)	C (x_3, y_3)
Distance from plant, feet		$q_1 = 1.50$	$q_1+q_2=15.0$	$q_1+q_2+q_3=22.3$
Available water content	%	$P_1=6.80$	$P_2=8.20$	$P_3=9.70$
	lbs./cu. ft.*	5.52	6.66	7.88

*Pounds soil/cu. ft. =gm soil/cc ×cc/cu. ft. ×lbs./gm
$= \text{gm/cc} \times (2.540\times 12)^3 \times 0.0022046 = \text{gm/cc} \times 62.43$

$$\text{Gm soil/cc} = \text{Volume-wt.} = \frac{\text{wt. sample of soil}}{\text{volume it occupied}} = \text{apparent density.}$$

$$\text{With a soil volume-wt. of 1.3, lbs. water/cu. ft.} = \frac{\%H_2O}{100}\times 1.3\times 62.43 = \%H_2O\times 0.812$$

The two-point form of an equation for a straight line, from geometry (1), is

$$\frac{x-x_1}{y-y_1} = \frac{x_2-x_1}{y_2-y_1} \tag{2}$$

When this is solved for y and rearranged,

$$y = \left[\frac{y_2-y_1}{x_2-x_1}\right]x + \left[y_1 - \frac{y_2-y_1}{x_2-x_1}\cdot x_1\right] \tag{3}$$

A comparison of equation (3) to (1) shows

$$m = \frac{y_2-y_1}{x_2-x_1};\ \text{and}\ b = y_1 - \frac{y_2-y_1}{x_2-x_1}\cdot x_1 \tag{4}$$

Taking values (x_1y_1) and (x_2y_2) from the table corresponding to straight line AB (Fig. 1) and assuming the volume-weight is 1.3,

$$m_1 = \frac{y_2-y_1}{x_2-x_1} = \frac{(8.2-6.8)\ 1.3\times 62.43}{100\ (15.0-1.5)} = 0.0842 \tag{5}$$

$$b_1 = \frac{6.8}{100}\times 1.3\times 62.43 - 0.0842\times 1.5 = 5.52-0.13 = 5.39 \tag{6}$$

and,

$$y = 0.0842x + 5.39 \tag{7}$$

Or from values (x_1y_1) and (x_3y_3) from the table corresponding to the straight line AC in Fig. 1:

$$m_2 = \frac{y_3-y_1}{x_3-x_1} = \frac{(9.7-6.8)\ 1.3\times 62.43}{100\ (22.3-1.5)} = 0.113 \tag{8}$$

$$b_2 = \frac{6.8}{100}\times 1.3\times 62.43 - 0.113\times 1.5 = 5.52-0.17 = 5.35 \tag{9}$$

and,

$$y = 0.113x + 5.35$$

These specific cases illustrate the general expression (1) $y=mx+b$ in which m and b are expressed in terms of soil moisture by means of expression (4) and the values in Table 1:

$$m = \frac{y_2-y_1}{x_2-x_1} = \frac{(P_2-P_1)\times \text{Vol. wt.}\times 62.43}{100\times q_2} = \frac{\text{Vol. wt.}\times 62.43}{100}\ \frac{P_2-P_1}{q_2} \tag{10}$$

$$b = y_1 - \frac{y_2 - y_1}{x_2 - x_1} x_1 = \frac{P_1}{100} \times \text{Vol wt.} \times 62.43 - mq_1$$

$$= \frac{P_1}{100} \times \text{Vol. wt.} \times 62.43 - \frac{(P_2 - P_1)\ \text{Vol. wt.} \times 62.43 \times q_1}{100\ q_2}$$

$$= \frac{\text{Vol. wt.} \times 62.43}{100}\left[P_1 - \frac{(P_2 - P_1)\ q_1}{q_2}\right] = \frac{\text{Vol. wt.} \times 62.43}{100}\left[P_1 - (P_2 - P_1)\ \frac{q_1}{q_2}\right] \quad (11)$$

P_1 is the percentage of water at q_1 feet from the plant and P_2 is the percentage of water at $q_1 + q_2$ feet from the plant (b is the moisture content under the plant, and is the content P_1 at q_1, less the difference $P_2 - P_1$ multiplied by the ratio of distances q_1/q_2).

THE SUMMATION OR INTEGRATION OF MOISTURE CONTENT IN A SQUARE AREA SURROUNDING EACH PLANT

The most common spacing of plants is in the form of squares (Fig. 2). Each plant (or hill) may be considered to have the space KMQT

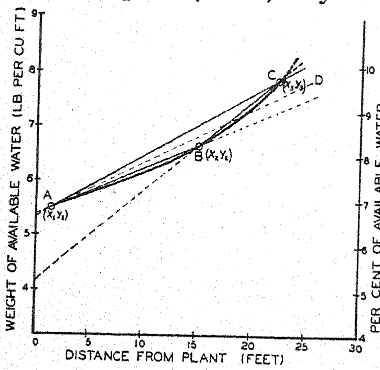

FIG. 1.—Increase in available water with distance from a plant.

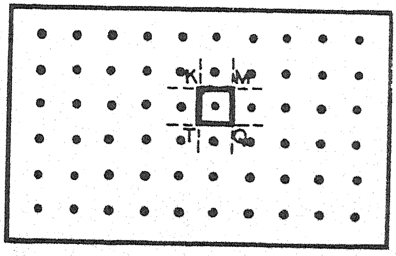

FIG. 2.—Spacing of plants giving water availability as squares.

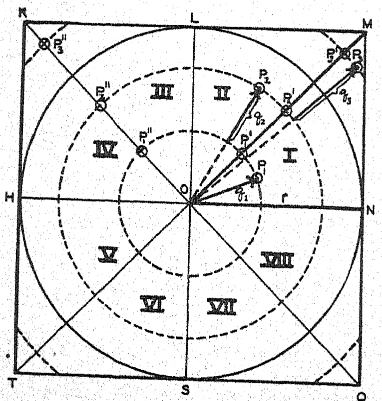

FIG. 3.—Distribution of water around a plant (at o) with plant spacing as squares.

(Figs. 2 and 3) from which to secure water and nutrient materials. Samples for moisture content are taken at measured distances from the plant. At a given distance, q_1 feet, the percentage of water is $P_1 (= P_1' = P_1''$ etc.). At q_2 feet further from the plant there is $P_2 (= P_2' = P_2''$ etc.) per cent of water. P_2 is greater than P_1 because the samples are taken at a greater distance where there is a lower root concentration. Still other samples might be taken at q_3 feet farther from the plant. This is the way in which the percentage data were obtained for Table 1 and Fig. 1.

Polar coordinates are more suitable than rectangular coordinates in solving this problem in which the moisture is assumed to increase uniformly from a center (or radially). Instead of the usual ordinates and abscissas (vertical and horizontal), the position of any point is defined as a certain distance *f* from the point of origin, *O*, measured at an angle ϕ from the horizontal base line ON (Fig. 4). Any point in a plane is defined by giving its two coordinates f and ϕ.

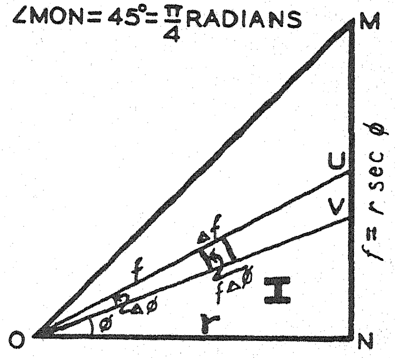

FIG. 4.—Segment *mon* taken from Fig. 3, showing integration process with polar coordinates.

In a right triangle such as NOV

$$\text{secant } \phi = \frac{\text{hypotenuse}}{\text{side adjacent angle } \phi} = \frac{\text{OV}}{\text{ON}}; \text{ and OV} = \text{ON secant } \phi. \text{ Since}$$

ON = r and OV = f, the equation for line MN, in polar coordinates, is

$$f = r \sec \phi \tag{12}$$

Since the moisture content increases with distance uniformly about the plant, only a portion of the area from which moisture is drawn needs to be considered in the integration. The distribution of moisture in MON (Figs. 3, 4) is repeated eight times about the plant. Angle MON is 45° or $\frac{\pi}{4}$ radians, while ON = r is half the distance between plants in a row. The following application of calculus evaluates the amount of water contained in the soil volume represented by the area of triangle MON in a stratum of 1 foot thickness.

Calculus is designed to give the summation for the whole area MON of all the small units of water contained in corresponding small units of soil, any one of which is represented by the small rectangle in Fig. 4. The sides of the rectangles become infinitesimally small and the number of rectangles increases infinitely. The rectangle is the upper base of a prism of soil 1 foot high. The dimensions of the small unit of soil are unity, Δf, and f $\times \Delta\phi$ in which f is expressed in feet and angle ϕ is expressed in radians. The small amount of water ΔW in this unit of soil is dependent on its volume and its distance from the plant, that is,

$$\Delta W = F(f) \times \text{volume of unit} = F(f)\, f\, \Delta f\, \Delta\phi \tag{13}$$

in which F (f) is the function of f expressing the relationship between water content of the soil and distance from the plant. This relationship was shown to be y = mx + b when m and b were expressed in appropriate units as in equations (10) and (11). This equation may be written as a function of x: F (x) = mx + b and since x may signify distance from the plant in any direction, as does f,

$$F(f) = mf + b \tag{14}$$

For convenience the values of m and b in terms of soil moisture constants are not substituted until after integration.

Substituting the value of F (f) from equation (14) in (13),

$$\Delta W = (mf + b)\, f\, \Delta f\, \Delta\phi \tag{15}$$

Recalling that the total water (W) available to the plant is 8 times the amount in triangle MON, and that the triangle (Fig. 4) is bounded by the line MN whose equation (12) is $f = r \sec\phi$, and lines OM and ON (the values of f at $\phi = 0$ and $\phi = 45°$), we may write,

$$W = 8 \lim_{\substack{\Delta f \to 0 \\ \Delta\phi \to 0}} \sum_{\phi_1 = 0}^{\phi_2 = 45°} \sum_{f_1 = 0}^{f_2 = r \sec\phi} (mf + b)\, f\, \Delta f\, \Delta\phi$$

In the limit, differential quantities are used, and

$$W = 8 \int_{\phi_1 = 0}^{\phi_2 = 45°} \int_{f_1 = 0}^{f_2 = r \sec\phi} (mf + b)\, f\, df\, d\phi = 8 \int_0^{45°} \int_0^{r \sec\phi} (mf^2 + bf)\, df\, d\phi \tag{16}$$

When equation (16) is integrated (1) first with respect to f, and then ϕ

$$W = 8 \int_0^{45°} \left[\frac{mf^3}{3} + \frac{bf^2}{2}\right]_0^{r \sec\phi} d\phi = 8 \int_0^{45°} \left[\frac{mr^3 \sec^3\phi}{3} + \frac{br^2 \sec^2\phi}{2}\right] d\phi$$

$$= \frac{8mr^3}{3} \int_0^{45°} \sec^3\phi\, d\phi + \frac{8br^2}{2} \int_0^{45°} \sec^2\phi\, d\phi$$

$$W = \frac{8mr^3}{3 \times 2} \Big[\sec\phi \tan\phi + 2.303 \log_{10} (\sec\phi + \tan\phi)\Big]_0^{45°} + 4br^2 \Big[\tan\phi\Big]_0^{45°} \tag{17}$$

$$= \frac{4mr^3}{3} (\sqrt{2} + 2.303 \log_{10} 2.414) + 4br^2 = \frac{4mr^3}{3} (1.414 + 0.881) + 4br^2$$

$$W = \frac{4 \times 2.295}{3} mr^3 + 4br^2 \tag{18}$$

The amount of water in the plat taken as an example is calculated from equation (18) as follows: In equation (5) and (6), $m_1 = 0.0842$ and $b_1 = 5.39$. Taking 30 feet as the distance between plants, or $r = 15$ feet,

$$W = \frac{4 \times 2.295}{3} \times 0.0842 \times (15)^3 + 4 \times 5.39 \times (15)^2 = 5{,}720 \text{ pounds.} \tag{19}$$

This means that there are 5,720 pounds of water in the 1-foot section of earth, 30×30 feet in area, for which the moisture percentages were known. Equation (18) is transformed into more readily usable forms in following paragraphs.

GENERAL FORMULAS FOR ANALYSIS OF FIELD DATA

Equation (18) above gives the relationship between the plant distribution (r), water distribution (m, b) and the available water present (W).

$$W = \frac{4 \times 2.295}{3} mr^3 + 4br^2$$

Substituting from equations (10) and (11) the values of m and b expressed in terms of soil moisture constants,

$$W=\frac{4\times 2.295}{3}\left[\frac{\text{Vol.wt.}\times 62.43}{100}\,\frac{P_2-P_1}{q_2}\right]r^3+4\left[\frac{\text{Vol.wt.}\times 62.43}{100}\left(P_1-\frac{(P_2-P_1)q_1}{q_2}\right)\right]r^2$$

$$W=\frac{4\times 2.295\times 62.43}{3\times 100}\times\text{Vol. wt.}\times r^3\,\frac{P_2-P_1}{q_2}+\frac{4\times 62.43}{100}$$

$$\times\text{Vol. wt.}\times r^2\times\left[P_1-\frac{(P_2-P_1)\,q_1}{q_2}\right]$$

$$\mathbf{W=1.9104\times Vol.\ wt.\times r^3\left[\frac{P_2-P_1}{q_2}\right]+2.4972\times Vol.\ wt.\times r^2\left[P_1-\frac{(P_2-P_1)\,q_1}{q_2}\right]} \quad (20)$$

$P_1=\%$ water at q_1 distance, and $P_2=\%$ water at q_1+q_2 distance.

The volume-weight may be determined with the same samples as used for moisture determinations. In loess and similar material the volume-weight is approximately 1.30. For illustrative purposes the spacing of plants in the row is taken as 30 feet between centers. Then r is 15 feet. Substituting in equation (20),

$$W=1.9104\times 1.30\times(15)^3\frac{P_2-P_1}{q_2}+2.4972\times 1.3\times(15)^2\left[P_1-\frac{(P_2-P_1)\,q_1}{q_2}\right]$$

$$W=8382\frac{(P_2-P_1)}{q_2}+730.4\left[P_1-\frac{(P_2-P_1)\,q_1}{q_2}\right] \quad (21)$$

This simplified form of the equation applies to a whole field of a given spacing, and the weight of water for a given plant (or hill) in a 1-foot section of earth is computed from the percentages of water at known distances from the plant. In Table 1, $P_1=6.8\%$, at $q_1=1.5$ feet from plant, and $P_2=8.2\%$, at $q_2=13.5$ feet further from the plant. These data substituted in equation (21) give:

$$W=8382\frac{8.2-6.8}{13.5}+730.4\left[6.8-\frac{(8.2-6.8)}{13.5}\times 1.5\right] \quad (22)$$

The quantity $\frac{P_2-P_1}{q_2}=\frac{8.2-6.8}{13.5}=0.1037$ may be substituted twice in evaluating (22):

$$W=8382\times 0.1037+730.4\ (6.8-0.1037\times 1.5)=5720\text{ pounds} \quad (23)$$

This is the weight of water in a 1-foot section of 30×30 foot area, which is the same value as in equation (19).

APPLICATION OF THE FORMULAS TO MOISTURE DATA

In order to obtain the total amount of available water in a 25 or 30 foot section of earth through which tree roots penetrate, or in a shallower section for most other plants, several of the following steps would be taken. A plot of the moisture data is drawn such as illustrated in Fig. 5. The moisture percentages may conveniently be plotted on the horizontal axis and depth on the vertical axis. The hygroscopic coefficient percentage may be shown at the left of the

vertical axis thus leaving at the right of the axis only available water content, on which the plant depends for its moisture supply. The second step is to divide the available water curve into regions. In some depth ranges, moisture content may not vary with distance from the plant. For example, periodic rainfall wets the surface 4 feet (region A, Fig. 5); at 12 to 18 feet (region C) substantially all of the available water is gone; below 26 feet (region E) little of the available water is used. At any one of these depth ranges (regions A, C, E), the weight of water may be computed in the usual way:

$$W = \frac{\%\ \text{water}}{100} \times \text{Vol. wt.} \times 62.43 \times \text{Soil Volume} \tag{24}$$

Volume is in cubic feet and is equal to the product of the area occupied by the plant and the depth of the region in question.

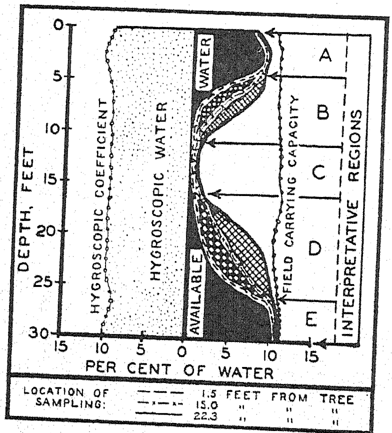

FIG. 5.—Variations in water content with depth in earth at various distances from a tree.

Where the moisture content varies with distance from a plant (as in regions B and D, Fig. 5), the integrated equations (20) and (21) are designed to give the weight of water. Considerably over one-half the available water may be used near the plant when less than one-fourth of it is used at the periphery of the area of water availability. A separate substitution is ordinarily required for each foot of depth; however, for a given set of field conditions, the successive applications after one evaluation of a 1-foot section are more simple because of the repetition of several factors.

The following equations are useful in interpreting the moisture data obtained from the integrated equations (20) and (21) and the unintegrated equation (24). When W_F is the water contained by soil or subsoil at the field carrying capacity (FCC),

$$W_F = \frac{\text{FCC}}{100} \times \text{Vol. wt.} \times 62.43 \times \text{Soil Volume}$$

Soil volume is expressed in cubic feet. Similarly unavailable water W_U, is expressed by

$$W_U = \frac{\text{H.C.}}{100} \times \text{Vol. wt.} \times 62.43 \times \text{Soil Volume}$$

in which H.C. is the percentage of unavailable water (2). Then available water W_A present in a soil or subsoil at its field carrying capacity is expressed as $W_A = W_F - W_U$. In previous equations, W is obtained in terms of available water present when the moisture data used are percentages of available water, i.e., total per cent water

minus the hygroscopic coefficient. If the original subsoil-moisture content was the field carrying capacity, then the proportion of the originally available water already used by plants at the time of sampling is expressed by the following:

$$\text{Per cent of the available water remaining} = \frac{W}{W_A} \times 100 \tag{25}$$

MODIFICATIONS OF THE FORMULAS FOR OTHER UNITS AND MOISTURE DISTRIBUTION

UNITS

For sampling depth-intervals of 2, ½, ⅓, or other factors of a foot, equations (20) and (21) are evaluated as previously discussed and the results are multiplied by 2, ½, ⅓, or other factors of a foot used in sampling. Units other than feet and pounds may be used by modifying the numerical constants in equation (20).

MOISTURE DISTRIBUTION

The water content does not increase exactly in proportion to distance from the plant as shown by the curve formed by the three points. A closer approximation is obtained by averaging the value found in equations (19) or (23) with that obtained by the use of a third moisture percentage P_3 at C (Fig. 1). This involves the use of line AC with slope and intercept determined in equations (8) and (9). The coordinates for $A(x_1y_1)$ and $C(x_3y_3)$ from Table 1 are substituted into equation (21). The sampling distances in this case are feet from 0 to P_1 and from P_1' to P_3' (Fig. 3), thus q_2 in the equation is replaced by q_2+q_3.

$$W = 8382\,\frac{P_3-P_1}{q_2+q_3} + 730.4\left[P_1 - \frac{(P_3-P_1)\,q_1}{q_2+q_3}\right]$$

$$W = 8382\,\frac{9.7-6.8}{22.3-1.5} + 730.4\left[6.8 - \frac{9.7-6.8}{22.3-1.5}\times 1.5\right] = 5{,}982 \text{ pounds} \tag{26}$$

$$\text{Taking the average of significant figures, } \frac{5980+5720}{2} = 5{,}850 \text{ pounds of water.} \tag{27}$$

This represents the evaluation of equation (21) for the mean line AD (Fig. 1).

The curve ABC may be approximated along lines AB and BC (Fig. 1) as follows when OP_2 (Fig. 3) is less than r: The values m and b for line BC are first calculated from $B(x_2y_2)$ and $C(x_3y_3)$, and the amount of water (W_{BC}) is obtained by the use of equation (18). The amount of water (W_1) in a circle of radius OP_2 (Fig. 3) is found using these same values of m and b, by equation (34) explained below. The distance OP_2 is the value of r_3. The amount of water (W_2) in the circle of radius OP_2 is next calculated using equation (34) with the values of m and b for line AB computed for points $A(x_1y_1)$ and $B(x_2y_2)$. Whence, the water content, W, of KMQT, based on lines AB and BC, is

$$W = W_{BC} - W_1 + W_2 \tag{28}$$

The weight of water may be estimated more closely if the equation of the curve ABC is found analytically. The equation would give y as another function of x or f, as

$$y = F'(x) = F'(f) \tag{29}$$

This new function, F′ (f) could be substituted in equations (13) and (16) and integrated, though possibly with some difficulty.

Water content increases slightly more rapidly toward M than toward N in Fig. 4 because the surrounding plants are further from the line OM than the line ON. Further sampling would permit the analytical expression of water content as a function of distance from the plant and angular rotation ϕ from the line ON, thus $W = F''(f,\phi)$. This expression might be substituted for F (f) in equations (13) and (16) and its integration would give a still more exact expression of water content. It is believed that relative errors in sampling and other manipulations would make such exhaustive mathematical application impracticable.

MODIFICATIONS FOR PLANT SPACINGS

SQUARES

The integration is based on arrangement of plants in the form of squares, and this is a common arrangement. Brief consideration is now given to two other possible plant arrangements and the method of obtaining water content for the simplest case in which the water increase is proportional to the distance from the plant.

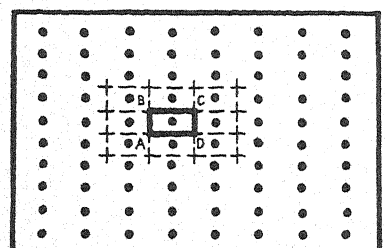

FIG. 6.—Spacing of plants with greater distance between rows than between plants in a row, giving water availability as rectangles (not squares).

RECTANGLES IN GENERAL

The case may arise when space between plants in the row is less than the space between the rows (Fig. 6). Each plant may draw moisture from the area ABCD (Figs. 6, 7). The available water remaining may be computed from modified forms of the integrated equation (17). The weight of water, W, is obtained as two sums, W_I corresponding to the water in the four areas labeled I, and W_{II} corresponding to that in the four areas labeled II (Fig. 7). The situation is as follows:

$$W_I = \tfrac{1}{2} \times \left[\text{equation (17) evaluated for } r_1 \text{ and angle } \phi_1 = 0,\ \phi_2 = \text{COE}\right] \tag{30}$$

$$W_{II} \times \tfrac{1}{2} \times \left[\text{equation (17) evaluated for } r_2 \text{ and angle } \phi_1 = 0,\ \phi_2 = \text{COH}\right] \tag{31}$$

Total water, W, in ABCD is

$$W = W_I + W_{II} \tag{32}$$

The values for r_1, r_2 and angles COE and COH are found for a given field by the inter-row and inter-plant distances as indicated in Fig. 7. The numerical values of logarithms, tangent ϕ, and secant ϕ are given in tables (3).

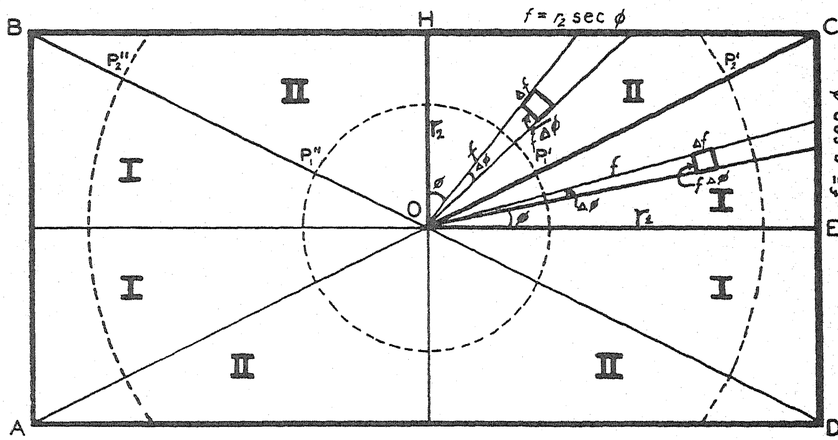

FIG. 7.—Method of applying formula for water content with rectangular (not square) spacing of plants.

HEXAGONS AND OTHER FIGURES APPROACHING CIRCLES

In the arrangement of plants shown in Fig. 8, the distance between plants in a row is equal to the distance between the rows. Each plant

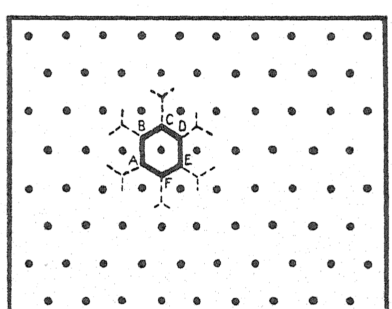

FIG. 8.—Alternate plant spacing, giving water availability as hexagons.

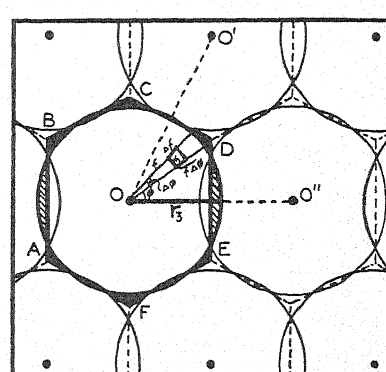

FIG. 9.—Circle approximation of hexagonal area and integral limits for water content.

has the hexagonal space ABCDEF from which to draw moisture. A circle of radius r_3 (Fig. 9), having the plant at o as its center, has an area equivalent to the area of the hexagon. The water content W is found by integration of an equation set up exactly as in equation (16)

except that the limits are the circle $f_1=0$, $f_2=r_3$ and $\phi_1=0$, $\phi_2=360°=2\pi$ radians:

$$W=\int_{\phi_1=0}^{\phi_2=2\pi}\int_{f_1=0}^{f_2=r_3}(mf+b)\,f\,df\,d\phi=\int_0^{2\pi}\left[\frac{mr_3^3}{3}+\frac{br_3^2}{2}\right]d\phi \tag{33}$$

$$W=2\pi\left[\frac{mr_3^3}{3}+\frac{br_3^2}{2}\right] \tag{34}$$

in which m and b are defined by equations (10) and (11) and r_3 is $0.505\times$line oo′ or $0.565\times$line oo″ (Fig. 9). These ratios for r_3 were computed as follows: The area of the hexagon was determined from the geometry of a plot on graph paper; the radius r_3 of a circle having this area was computed; and the ratios

$$\frac{r_3}{oo'}=0.505 \text{ and } \frac{r_3}{oo''}=0.565 \tag{35}$$

were then taken.

SUMMARY

In certain orchard, lysimeter, and other moisture studies, the water content of soil and substrata is not uniform but varies systematically. The calculation of the weight of water in soil or subsoil materials in which the water content varies with distance from a plant is considered. Formulas are derived by a procedure analogous to that used in deriving the formula for the area of a circle. The use of the formulas requires the use of simple arithmetic only.

Three possible arrangements of plants are considered. With plants arranged in checker-board fashion, i.e., as squares, the weight of water available to each plant in a given foot of depth is approximated closely by formula (20). A condensed formula for a given field may be prepared according to the illustrative formula (21). A separate substitution is usually required for each foot or other individual sampling depth. These formulas are not required, of course, in any sampling depth ranges in which water content does not vary with distance from the plant.

With plants arranged with more space between rows than between plants in a row, equations (30), (31), and (32) are used. Tables must be consulted for evaluating the constants for a given field, after which calculations are easily carried out. In alternate plant spacing with inter-plant and inter-row distances approximately equal (Fig. 8), the formula (34) is used.

The curve in Fig. 1 is an example of the increase in moisture content with distance from a tree. The derivations take into account the increasingly greater amounts of soil volume corresponding to the moisture content at sampling positions successively further from a plant. A simple average moisture content for the whole area would not take this into account, nor can a satisfactory approximate weighted average be obtained. The assumptions made in the derivations, on the other hand, give an aggregate error of but a few per cent at most.

LITERATURE CITED

1. GRANVILLE, W. A., SMITH, P. F., and LONGLEY, W. R. Differential and Integral Calculus. Boston:Ginn and Co. 1934. (Pages 1–3, 225, and 512.)
2. KIESSELBACH, T. A., RUSSEL, J. C., and ANDERSON, ARTHUR. The Significance of Subsoil Moisture in Alfalfa Production. Jour. Amer. Soc. Agron., 21:241–268. 1929.
3. HODGMAN, C. D., and LANGE, N. A. Handbook of Chemistry and Physics. Cleveland:Chemical Rubber Pub. Co.
4. WIGGANS, C. C. The Effect of Orchard Plants on Subsoil Moisture. Proc. Amer. Soc. Hort. Sci., 33:103–107. 1935.
5. ———. Some Further Observations on the Depletion of Subsoil Moisture by Apple Trees. Proc. Amer. Soc. Hort. Sci., 34:160–163. 1936.

A CRINKLED LEAF MUTATION IN ALFALFA[1]

T. E. ODLAND AND ROBERT LEPPER, JR.[2]

BREEDING work with alfalfa has been in progress at the Rhode Island Agricultural Experiment Station for the past 10 years. In another paper[3] the methods and materials used and some of the results obtained in the study of flower color inheritance have been presented. Among other strains, selections, and hybrids obtained from various sources was an F_1 hybrid obtained from the Cornell Experiment Station. This cross was studied by Moe[4] at British Columbia and at Cornell University. The hybrid resulted from a cross between *M. sativa* and *M. falcata*.

In this hybrid an abnormality in the F_2 occurred which causes a crinkling of the leaf (Fig. 1). In this abnormality the leaf appears puckered and the margin has an irregular conformation due to an extension of tissue at the periphery. The abnormality was apparently brought about by the epidermis and mesophyll growing at a more rapid rate than the vascular tissue. The presence of a large amount of crinkled leaf was detrimental to the plant and resulted in stunted growth and a very limited production of flowers or seed.

The crinkled condition was not apparent in the F_1 generation. An F_2 progeny of 418 plants, 244 were normal, being without crinkle, and 174 plants had varying degrees of it (Fig. 2). Comparison of the observed and the calculated data, as shown below, suggests a trifactorial basis for this character:

	Normal	Crinkle	Total
Observed	244	174	418
Calculated	242	176	418
Difference	+2	—2	0

A difference of 2 with a probable error of 7 indicates the closeness of the fit.

Complementary dominant factors D and E are assumed to be present in the normal plant. It is suggested that the absence of one or the other produces the crinkled character. Dominant Cr produces crinkle except in the presence of D and E. The triple recessive also results in normal plants. On this basis, the genetic makeup of two normal-appearing parents for the crinkled leaf condition could be DDEECrCr and ddeecrcr. In the F_2 a 37:27 ratio of normal to crinkle would be expected. In the cross studied it appears probable that the mutation from cr to Cr occurred in the F_1.

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[1]Published by permission of the Director of Research, Rhode Island Agricultural Experiment Station, Kingston, R. I. as contribution No. 534. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1938. Received for publication November 23, 1938.

[2]Agronomist and Former Graduate Assistant, respectively.

[3]LEPPER, R. JR., and ODLAND, T. E. Inheritance of flower color in alfalfa. Unpublished data.

[4]MOE, G. G. Alfalfa studies. A preliminary study of the inheritance of certain morphological characters. Unpublished thesis, Cornell University. 1928.

The crinkled condition existed in varying degrees in those plants which possessed the character. The occurrence of the several degrees of crinkle might be explained as the result of the influence of a number of modifying factors that were present in varying amounts in these plants.

The behavior of F_3 families (Table 1) grown from plants with no crinkle, little crinkle, medium crinkle, and much crinkle is difficult to explain. Ten genotypes which are phenotypically crinkled and would allow only for the production of crinkled

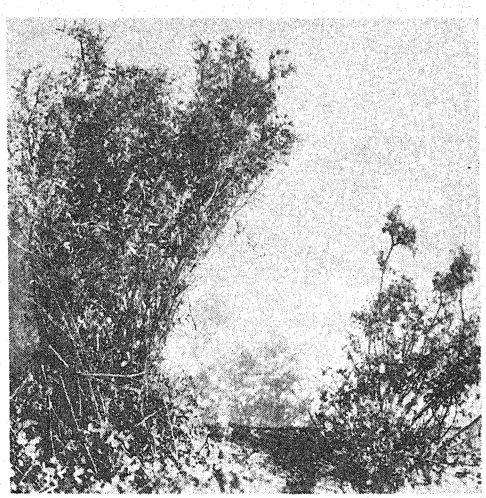

FIG. 1.—Normal plant, left, and crinkled leaf plant, right.

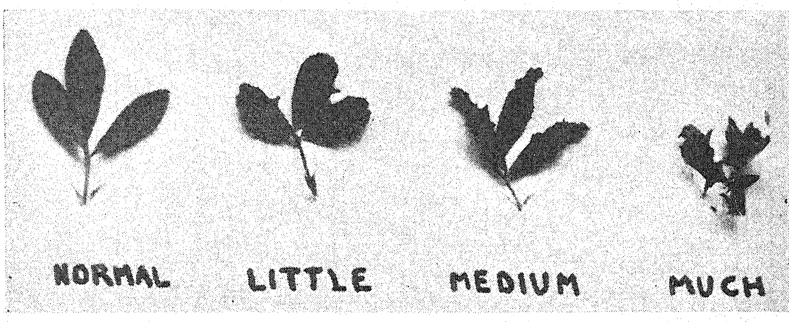

FIG. 2.—Degrees of crinkled leaf in alfalfa (F_2–20).

TABLE 1.—*Segregation for crinkled leaf in F_3 families.*

Degree of crinkle in the F_2	F_3 generation	Normal 0	Crinkle 1–9	Combined numbers
0	F_3–20–3	20	..	
	F_3–20–5	12	..	
	F_3–20–6	5	..	44 normal
	F_3–20–8	5	1	1 crinkle
	F_3–20–13	2	..	
1	F_3–20–1	9	7	28 normal
	F_3–20–9	2	1	8 crinkle
	F_3–20–2	17	..	
5	F_3–20–4	2	..	19 normal
	F_3–20–10	5	7	24 crinkle
	F_3–20–11	12	17	
9	F_3–20–7	..	1	7 normal
	F_3–20–12	7	15	16 crinkle

progeny are theoretically possible. It is assumed that those plants which have crinkle to a large degree and which would produce only crinkle in their progenies fail to produce seed. The crinkled plants that do produce seeds would be those types which segregate for both crinkle and normal.

According to theory, nine possible genotypes with normal expression exist which may segregate and four which may not. As Table 1 shows, those progenies grown from selfed F_2 plants possessing no crinkle produced only normal plants except in one case. This may be attributed to the fact that the progenies were small and crinkled individuals which should appear in the minority have consequently not appeared.

The fact that large numbers of crinkled individuals appear in proportion to normal plants, as the parent ranges from normal to much crinkle, suggests the possibility that various degrees of crinkle depend upon the genotypes and the individual factors involved.

THE RELATIONSHIP BETWEEN THE ORIGIN OF SELFED LINES OF CORN AND THEIR VALUE IN HYBRID COMBINATION[1]

SHAO-KWEI WU[2]

MODERN methods of corn breeding are characterized by the development of inbred lines and their use in hybrids. Extensive studies have been made of methods of breeding improved inbred lines and of prediction of the probable yielding ability of inbred lines in commercial hybrids on the basis of their combining ability with other inbred lines used as testers, or their combining ability in top crosses. The primary purposes of many of these studies were to find some method of discarding undesirable inbreds at as early stage as possible and the development of the best yielding inbreds that combine well in crosses.

In the past there have been very few controlled studies of the relationship between hybrid vigor and the origin of the inbred lines. It is the purpose of this study to present experimental results on the combining ability of inbred lines in single crosses in relation to the genetic origin of the lines.

Publications concerning the modern method of corn breeding are voluminous and have been reviewed extensively by Hayes, Hayes and Garber, Jenkins, and Richey.[3] The reader is referred to these papers for a comprehensive review of the subject.

MATERIAL AND METHOD

The inbred lines used were furnished by the Division of Agronomy and Plant Genetics, University of Minnesota, and were especially favorable ones for a study of combining ability in relation to their origin. They were obtained by the pedigree method of breeding by selfing after crosses were made among the parental inbred lines in such a way that at least one of the parents in each cross had considerably more than average ability to withstand lodging. The resulting lines, produced by selfing for six or more generations after the crosses were made, were rather outstanding in ability to withstand lodging. These lines were homozygous

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1661 of the Journal Series, Minnesota Agricultural Experiment Station. Part of a thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy at the University of Minnesota. Received for publication November 23, 1938.

[2]The recipient of the Anhwei Provincial Research Fellowship, Anhwei, China. The writer wishes to express his sincere appreciation to Dr. H. K. Hayes, under whose direction this study was made, to Dr. I. J. Johnson for his advice regarding many phases of the field work, and to Dr. F. R. Immer for advice regarding the analysis of the data.

[3]HAYES, H. K. Methods of plant breeding. Nat. Agr. Res. Bureau, Nanking, China. 1937.

HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co. Ed. 2. 1927.

JENKINS, M. T. Corn improvement. U. S. D. A. Yearbook, 1936: 455–522. 1936.

RICHEY, F. D. Corn breeding. U. S. D. A. Bul. 1489. 1927.

for yellow endosperm, appeared to be relatively vigorous, and had desirable seed and plant characters. The origin of the inbred lines used in making crosses for this study is given in Table 1.

TABLE 1.—*Origin of inbred lines of corn.*

Group	Original parental lines crossed	Culture number of the resulting inbred lines	Years selfed
I...........	49 x 9–29	160, 166, 168, 177, 185, 192, 197	6
II...........	15–28 x 8–29	232, 234, 239, 243, 245, 246	6
III...........	15–28 x 9–29	253, 260, 266, 275, 279, 283, 292, A-136	6
IV...........	43 x 47	A-157, A-158, A-162, A-163	8
V...........	49 x 64	A-89, A-90	6
VI...........	64 x H	A-96	6
VII...........	15–28 x H	A-147	6

Parental inbred cultures 43, 47, and 49 were obtained from Minn. No. 13, 64 was selected from Northwestern Dent, 15–28 from Rustler White Dent, H from Reid's Yellow Dent, 8–29 from Purdue Early Yellow Dent, and 9–29 from Osterland's Yellow Dent.

In 1935, single crosses were made between the inbred lines in the first three groups with reference to the original parental inbred lines from which the present inbred lines were obtained. The plan of crosses was as follows:

1. A set of single crosses, which will be later designated as group A, were made between the inbred lines produced from single crosses with both parents in common, i.e., by making all possible intercrosses between inbred lines within group I as shown in Table 1.
2. Single crosses, later designated as group B, were made between inbred lines with one parent in common, i.e., between each inbred line in group III with three lines in group II, although not with the same three lines in each case.
3. Single crosses, later designated as group C, were made between inbred lines with no parent in common, i.e., between each line in group 1 with any three lines in group II.
4. Inbred lines of each group were also crossed with Minnesota No. 13, an open-pollinated variety used as the male parent in the top crosses.

Yield trials were made in 1936 at University Farm, St. Paul, and in Meeker County, Minnesota. Randomized block arrangements were used in the yield trials, each group of single crosses and three checks being considered as a unit. Within a group there were three replications, using single row plats of 12 hills for each variety and cross. Three check varieties, namely, Minnesota No. 13, an adapted strain for Central Minnesota, and Minhybrids 401 and 402, the double crosses released by the Minnesota Agricultural Experiment Station for central Minnesota, were included and randomized with the crosses in each block.

At maturity, only hills with three stalks surrounded by hills with corn were harvested. Green weight of ears from each plat was taken in the field. Ears of each plat were put in a cloth bag and oven dried at University Farm to place yields on a dry matter basis and determine moisture content at harvest. Yields in bushels per acre were calculated on a 14% moisture basis.

Unfortunately, the summer of 1936 was unusually dry so that the trials planted in Meeker County only were harvested. Since the data obtained that year merely consisted of one complete set of crosses planted in Meeker County, the trials were repeated in 1937 at University Farm, St. Paul, at the branch experiment station at Morris, and in Meeker County. Seed for certain crosses in each of the

three groups was insufficient for the 1937 yield trials. Crosses of a similar nature made by the Division of Agronomy amd Plant Genetics were kindly furnished to the writer so that about the same number of crosses for each type of parental origin were available in 1937 as in the previous year. The origin of inbred lines used in these crosses is given in Table 1 as groups IV, V, VI, and VII. The data of the single and top crosses obtained from University Farm in 1937 were later discarded on account of drought.

The inbred lines and original parental inbred lines were also planted at University Farm from 1935 to 1937, inclusive, in duplicated, randomized, single-row plats in single plant hills 1 foot apart in the row. Measurements for different characters were taken each year.

EXPERIMENTAL RESULTS

STUDY OF CHARACTERS OF INBRED LINES OBTAINED BY CROSSING TWO PARENTAL INBREDS FOLLOWED BY SELECTION

Since the inbred lines were obtained by the pedigree method of selection after crosses were made between the original parental inbreds, it should be interesting to study the actual effects of this method in the improvement of the inbreds. In order to study differences between the inbred lines, the analyses of variance were calculated by the methods devised by Fisher.[4] Tests of significance to determine whether or not there were significant differences between the parents and their progenies and among the progenies themselves were made by reference to tables provided by Snedecor.[5] In Table 2 are given the means and the range of variability for each character studied, grouped according to the origin of the resulting lines. The F values are presented in Table 3.

The inbred lines varied significantly in each of the three trials in all but 2 of the 11 characters studied, namely, root volume in 1935 and percentage of smutted plants in 1935. In general, the means of the resulting lines were between the limits of the two parental inbred lines. In some instances, and for some characters, the selected lines exceeded the limits of the more desirable parental inbred and in a few cases significantly so.

Eleven of the progeny lines were earlier numerically, as shown by date of silking, and six, as shown by date of pollen shedding, than the earliest parental lines, and four for each character were significantly so. No progeny line was significantly later than its later parent. Apparently, selection for earliness was practiced during the six generations of inbreeding and such selection was successful. The recovery of early maturing lines from the crosses of 15–28 and 8–29, early and late parental lines, respectively, clearly shows the effect of selection for this character.

Pulling resistance of the plants in culture 283 in the cross of 15–28 and 9–29 exceeded both parents significantly. This fact is interesting in view of the fact that one of the parents, culture 9–29, had been selected originally as very resistant to lodging. With this one excep-

[4]FISHER, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 6. 1936.

[5]Snedecor, G. W. Statistical Methods. Ames, Iowa: Collegiate Press, Inc. 1937.

TABLE 2.—*Means and ranges of variability of different characters of parental inbred lines and their progenies grown in replicated plats at University Farm, 1935–1937.*

Parental inbreds and progeny lines	No. of lines	Date of silking, July		Date of pollen shedding, July		Plant height, in.		Leaf area, sq. in.		Pulling resistance, lbs.		Root volume, c.c.	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
49	1	26.9		24.0		36.4		51.8		135.1		1,993.2	
8–29	1	41.2		38.7		55.2		78.8		338.0		6,737.8	
9–29	1	31.2		29.7		47.2		55.4		214.8		4,880.9	
15–28	1	31.1		27.3		34.5		62.1		139.6		3,829.9	
49x9–29	7	27.9	22.0–30.7	25.7	21.5–29.7	40.8	31.7–47.9	55.4	45.6–63.9	155.6	115.6–207.0	3,490.3	1,837.4–4,890.3
15–28x8–29	6	30.0	26.2–34.3	27.1	23.7–31.7	45.2	37.0–50.1	63.0	55.3–75.3	175.6	146.4–202.2	3,669.8	2,482.8–5,568.0
15–28x9–29	7	29.4	24.0–32.1	27.5	23.3–30.0	44.4	33.2–50.7	62.5	53.2–76.5	199.5	147.4–275.6	4,372.3	3,164.8–6,613.3

Parental inbreds and progeny lines	No. of lines	No. of brace roots underground		Ear height, in.		Ear length, cm.		Ear weight, grams		Percentage of smutted plants	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
49	1	25.2		11.2		9.6		54.6		15.0	
8–29	1	36.1		20.2		11.1		105.6		18.3	
9–29	1	36.7		22.9		10.8		78.8		3.0	
15–28	1	41.6		16.1		14.8		78.3		27.2	
49x9–29	7	32.6	24.2–43.3	16.2	5.8–22.9	11.3	9.0–13.8	62.5	14.4–105.2	14.2	2.9–21.4
15–28x8–29	6	32.3	26.4–41.2	18.1	11.9–22.9	12.6	10.9–13.7	65.9	59.0–76.4	24.0	6.9–54.2
15–28x9–29	7	37.6	32.6–45.0	19.3	13.6–27.4	12.8	8.0–16.4	81.2	46.6–108.6	19.2	1.0–43.6

TABLE 3.—*Analysis of variance of characters of inbred lines grown in 1935 to 1937.*

Character	Year of trial	D/F for cultures	F value	S.E. mean
Date of silking, July	1935	22	5.52**	1.59
	1936	23	7.20**	1.42
	1937	22	19.64**	0.88
Date of pollen shedding, July	1935	23	15.65**	0.78
	1936	23	4.74**	1.97
	1937	22	22.97**	0.73
Plant height, in.	1935	23	15.24**	1.50
	1936	23	10.13**	2.07
	1937	22	22.34**	1.38
Leaf area, sq. in.	1935	23	11.86**	2.94
	1936	23	9.91**	3.10
	1937	22	9.61**	2.70
Pulling resistance, lb.	1935	21	10.83**	11.81
	1936	23	7.12**	14.61
	1937	22	11.93**	19.23
Root volume, cc.	1935	21	1.61	203.50
	1936	23	2.42*	707.06
	1937	22	2.56*	1,231.34
No. of brace roots underground	1935	21	3.86**	2.97
	1936	23	3.23**	4.20
	1937	22	4.32**	1.95
Ear height, in.	1935	23	22.31**	1.15
	1936	23	17.54**	1.14
	1937	22	11.62**	1.06
Ear length, cm.	1935	22	9.41**	1.38
	1937	22	14.38**	0.48
Ear weight, grams	1935	22	2.63*	6.13
	1937	22	8.33**	9.15
Percentage of smutted plants	1935	22	1.88	4.72
	1936	23	2.60*	8.27
	1937	22	3.42**	8.55

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

tion, the other progeny lines did not reach the limit in pulling resistance of the more lodging resistant parent. All but one of the inbred lines were higher in pulling resistance than the lower parent and 13 of the 20 progeny lines gave significantly higher pulling resistance than the parent of lowest pulling resistance.

Culture 168 in the cross of 49×9–29 developed more brace roots underground than did either one of the parents. This culture was also fairly high in pulling resistance and root volume.

The progeny lines seemed to have been improved to a certain extent in smut resistance as there were 7 of the 20 progeny lines that were significantly lower in smut infection than the susceptible parent. However, none of them was significantly more resistant than the resistant parents in each group.

Culture 266 in the cross of 15–28 and 9–29 greatly exceeded either of the parents in root volume, although the parental lines, 15–28 and 9–29, were not significantly different in this character.

Six of the seven lines of the progenies from the cross of 49×9–29 produced as long or longer ears than did either parent. Culture 192 is

the only progeny in the three groups of crosses producing significantly longer ears than either parent.

With respect to ear weight, the progeny lines in the crosses of 49×9–29 and 15–28×9–29 varied in both directions beyond the limits of the two parents. Of the 14 progeny lines in these two groups, three cultures, 192, 283, and 292, produced ears significantly heavier than either parent. Culture 192 also produced significantly longer ears than either parent together with fairly good pulling resistance and root volume.

Considerable improvement was attained also for plant height in the cross of 15–28×9–29, as shown by culture 275 which exceeded the height of either parent, although this character was not particularly selected for in the course of inbreeding.

COMBINING ABILITY OF INBRED LINES IN SINGLE CROSSES IN RELATION TO THE GENETIC ORIGIN OF THE LINES

The combining ability of inbred lines in top crosses can be used to determine whether the material used was of comparable value for breeding purposes. In Table 4 are given the F values of the top crosses planted in Meeker County and at Morris, 1936 to 1937, inclusive.

TABLE 4.—*Analyses of variance of the yield of top crosses planted in Meeker County and at Morris, 1936 to 1937.*

Year of trial	Locality	D/F for crosses	F value
1936	Meeker County	25	2.46**
1937	Meeker County	34	1.29
1937	Morris	33	1.67*

*Exceeds 5% level of significance.
**Exceeds 1% level of significance.

As shown in Table 4, there were significant differences among the top crosses planted in Meeker County and at Morris, except that planted in Meeker County in 1937.

The average yields of top crosses for the seven groups in relation to genetic origin are summarized in Table 5.

TABLE 5.—*Average yield of top crosses by group in relation to genetic origin.*

Group	Origin	No. of crosses tested and average yield					
		No.	1936	No.	1937	No.	Av. 1936–37
			bu.		bu.		bu.
I	49 x 9–29	7	39.0	7	47.5	7	44.2
II	15–28 x 8–29	6	47.0	6	48.2	6	47.4
III	15–29 x 9–29	7	44.7	8	49.7	7	47.7
IV	43 x 47			4	49.3		
V	64 x 49			2	46.0		
VI	64 x H			1	48.7		
VII	15–28 x H			1	52.6		

The only wide differences noted were in Meeker County in 1936 where only three replications were used. In 1937, all groups gave rather similar yields in top crosses. Yields in the different groups were compared statistically and in 1936 the yields of top crosses in group I were significantly lower than groups II and III. It seems probable that the combining ability of inbred lines in group I was slightly lower than that of groups II and III.

The yield of single crosses in relation to their genetic origin are given in Table 6. Three check varieties were grown in randomized blocks with each group. Differences in yield within each group exceeded the 5% point and in all except two groups the 1% point.

The average yields of single crosses are given in Table 7.

A summary of yields in the three groups of single crosses is given in Table 7. The single crosses in group A, on the average, consistently yielded less than their check varieties and they also yielded less than either group B or group C, whereas, the differences between groups B and C were small and of little statistical significance.

The mean differences between the groups are compared in Table 8. The group differences were obtained by taking the mean yield of one group minus that of its check less the mean yield of the other group minus its check. The standard error of the group difference was computed by the formula, $S.E._{diff.} = \sqrt{\overline{S.E.^2_1}+\overline{S.E.^2_{ck1}}+\overline{S.E.^2_2}+\overline{S.E.^2_{ck2}}}$, where S.E. is the standard error of a mean.

From Table 8 it may be noted that, on the average, single crosses between lines where both of the parents were in common (group A) yielded significantly less than where only one of the parents was the same (group B) and less than where there were no parents in common (group C). It should be mentioned, however, that there were some exceptions to this for some single crosses gave good yields even tho they were bred from the selections of a single cross.

The vigor of single and double crosses has been explained on the basis of a dominance or partial dominance of growth factors, part of which are contributed by each of the inbred parents and the accumulation of a larger number of these dominant factors in the hybrid than in an inbred parent. On this basis, it would be expected, other things being equal, that greater hybrid vigor would be obtained between inbred lines of diverse genetic origin than from lines more closely related.

As improved inbred lines are bred by any of the recognized methods of breeding, including the pedigree method as used to produce the inbred lines used in this study, by backcrossing or by convergent improvement, it will be of great value to consider the origin of the lines in relation to their combining ability in crosses. It seems reasonable, as the results of this study indicate, that better hybrids can be expected, on the average, if the inbred lines are combined in crosses in such a manner that lines of diverse genetic origin are used for each particular experimental hybrid.

It seems probable that future breeding will consist of planned crosses which enable one to breed improved inbred lines through the combination of desirable characters of two or more parents, the test

TABLE 6.—*Yield of inbred lines in single crosses grouped according to the origin of the inbred lines.*

Group A*			
Variety or cross	1936 bu.	1937 bu.	Average 1936–37 bu.
Minn. No. 13	42.3	51.7	48.1
Minhybrid 401	45.8	64.4	57.6
Minhybrid 402	39.3	57.4	50.9
Mean	42.5	57.8	52.2
160×166	36.1	46.7	42.7
160×168	46.6	55.2	51.8
160×177	36.2	....	....
160×185	32.8	51.7	45.4
160×192	50.6	57.7	54.8
160×197	35.2	....	....
166×168	44.9	....	....
166×177	44.5	....	....
166×185	32.2	50.2	43.8
166×192	44.6	....	....
166×197	33.1	....	....
168×177	42.9	52.9	49.0
168×185	47.7	59.8	55.1
168×192	47.4	53.1	50.7
177×185	24.1	49.9	40.9
177×192	46.1	50.8	48.8
177×197	38.4	....	....
185×192	42.0	....	....
185×197		40.9	
A157×158		33.1	
A157×162		48.2	
A157×163		41.1	
A158×163		40.3	
Mean	40.3	48.8	48.3

Group B*			
Variety or cross	1936 bu.	1937 bu.	Average 1936–37 bu.
Minn. No. 13	24.1	54.3	43.8
Minhybrid 401	36.9	60.5	52.1
Minhybrid 402	31.1	48.8	42.5
	30.7	54.5	46.1
253×234	34.4	55.2	47.8
253×243	36.5	56.9	49.6
253×245	42.8	54.4	50.0
260×234	31.9	....	....
260×243	39.6	....	....
260×245	46.2	....	....
266×232	44.8	....	....
266×239	36.6	47.9	44.1
266×243	23.9	....	....
275×232	28.2	53.2	44.4
275×239	31.7	56.5	47.8
275×245	30.4	54.2	45.8
279×232	....	52.5	....
279×234	34.1	57.2	49.0
279×243	43.9	....	....
279×246	36.8	....	....
283×232	35.4	....	....
283×239	41.2	51.8	48.2
283×246	35.1	46.4	42.2
292×232	31.0	39.4	36.5
292×243	33.5	....	....
292×245	44.9	65.0	57.7
A147×96		49.2	
A147×136		53.7	
A 92×96		45.0	
	36.3	52.4	46.9

Group C*			
Variety or cross	1936 bu.	1937 bu.	Average 1936–37 bu.
Minn. No. 13	22.4	52.1	42.2
Minhybrid 401	37.8	59.0	51.9
Minhybrid 402	30.6	54.2	46.3
	30.3	55.1	46.8
160×232	32.3	47.2	42.2
160×239	41.6	49.0	46.5
160×245	34.1	....	....
166×232	34.2	42.3	39.6
166×243	53.2	56.5	55.4
166×245	38.2	51.3	45.5
168×232	35.0	42.4	40.0
168×234	34.5	....	....
168×239	50.3	57.5	55.1
177×232	43.0	52.3	49.2
177×243	43.5	66.2	58.7
177×246	23.2	....	....
185×234	35.8	62.2	53.4
185×243	44.9	57.5	53.3
185×245	31.7	....	....
192×232	43.0	47.8	46.2
192×239	38.0	62.6	54.4
192×246	39.0	....	....
197×234	42.4	....	....
197×239	30.8	59.4	49.8
197×246	25.7	....	
A158×89		55.7	
A158×136		60.4	
A158×147		58.5	
A 92×163		56.2	
A147×89		50.7	
A147×90		22.7	
	37.6	52.9	49.2

*Group A, representing a group of single crosses obtained from the crosses of inbred lines of a common genetic origin. Group B, representing a group of single crosses obtained from the crosses of inbred lines with one parentage in common. Group C, representing a group of single crosses obtained from the crosses of inbred lines with diverse genetic origin.

TABLE 7.—*Average yields of single crosses and check varieties in 1936 and 1937.*

Group of single crosses and checks	N	Mean	Percentage yield of crosses with checks as 100
1936			
Group A	18	40.3±0.86	94.9
Checks	3	42.5±2.11	
Group B	21	37.1±0.87	120.9
Checks	3	30.7±2.30	
Group C	21	37.6±1.04	124.1
Checks	3	30.3±2.74	
1937			
Group A	15	48.8±0.66	84.4
Checks	3	57.8±1.48	
Group B	16	52.4±0.72	96.1
Checks	3	54.5±1.67	
Group C	20	52.9±0.62	96.0
Checks	3	55.1±1.61	
Average, 1936–1937			
Group A	10	48.3±0.66	92.5
Checks	3	52.2±1.21	
Group B	12	46.9±0.68	101.7
Checks	3	46.1±1.35	
Group C	14	49.2±0.65	105.1
Checks	3	46.8±1.41	

TABLE 8.—*Differences in yield of single crosses grouped according to origin of the inbred lines.*

Differences between groups	Mean difference
1936	
A–B	−8.6±3.35
A–C	−9.5±3.71
B–C	−0.9±3.82
1937	
A–B	−6.9±2.44
A–C	−6.8±2.37
B–C	−0.1±2.57
Average, 1936–1937	
A–B	−4.7±2.05
A–C	−6.3±2.08
B–C	−3.2±2.17

of the combining ability in top crosses, a study of all possible combinations in single crosses of inbred lines of high top cross yielding ability, using only combinations of diverse origin, and the final yield trial of these double crosses that appear most desirable on the basis of previous single cross yields.

SUMMARY

1. The inbred lines furnished to the writer, on account of their diverse origin, were especially favorable for a study of the relationship between the genetic origin of the inbreds and the combining ability in single crosses.

2. Inbred lines used in making single crosses for this study were obtained by the pedigree method of breeding. Four original parental inbred lines, 49, 8–29, 9–29, and 15–28, descending from four different varieties, were involved in making crosses in such a way that in each cross one of the parents was highly desirable in withstanding lodging and the other in certain other agronomic characters. The inbred lines are divided into three groups according to their parentage, namely, group I, inbred lines being obtained from the crosses made between the original parental inbreds, 49 and 9–29; group II from the crosses made between 15–28 and 8–29; and group III from the crosses between 15–28 and 9–29.

3. Three groups of single crosses were made in 1935. Group A consisted of single crosses made between inbred lines of a common genetic origin using all possible crosses between seven inbred lines in group I; group B consisted of single crosses made between inbred lines with one original parent in common where each of eight inbreds in group III were crossed with three inbreds in group II; while group C consisted of single crosses between inbred lines of different genetic origin, i.e., crosses were made between each line in group I and three lines in group II. Additional single crosses were made from another five groups of inbred lines making three types of crosses similar to group A, B, C, to replace some of the single crosses lost in 1936 due to the drought.

4. In order to study the effect of the pedigree method of breeding upon the improvement of the inbred lines, 11 characters were measured on the progeny inbred lines as well as the original parental inbred lines. All of these characters but two showed significant variability, as shown by the analysis of variance. In general, the progeny lines varied between the limits of the two parents.

5. Selection for certain characters by the pedigree method of breeding was effective in isolating inbred lines more desirable in these characters than either parent. This is especially noticeable in the selection for earliness. The inbred lines, in general, showed a combination of desirable characters from both parents.

6. It has been noted that the single crosses made from inbred lines selected from a single cross yielded, on the average, consistently lower than the single crosses made from inbred lines with one parent in common, or the single crosses made from inbred lines of diverse genetic origin. There was no significant difference in yielding ability between the single crosses made from inbred lines with one parent in common and those made from inbred lines of entirely different genetic origin.

EFFECT OF FERTILIZERS AND METHOD OF THEIR APPLICATION ON NODULATION, GROWTH, AND NITROGEN CONTENT OF HAIRY VETCH[1]

T. H. ROGERS AND D. G. STURKIE[2]

THE use of various winter legumes for soil improvement is becoming general in the South, especially in Alabama. Hairy vetch (*Vicia villosa*) is one of the most important of these winter legumes. In order to obtain the best results with hairy vetch it is necessary to apply fertilizers, particularly phosphate, and to inoculate the plants. In the past farmers have been advised not to apply superphosphate in contact with the inoculant as it was thought that the phosphate would injure the inoculation. It has been recommended that basic slag could be applied in contact with the inoculant. In order to study the effect of fertilizers on inoculation and growth the experiment reported herein was conducted.

PLAN OF THE EXPERIMENT

This experiment was conducted at Auburn, Alabama, on a very light, Norfol sandy soil, on which vetch or Austrian winter peas had never grown. Each treatment was replicated four times and the replications were distributed systematically over the area. There were eight tiers, each containing 20 plats 16.5 by 27 feet, or 1/100 acre. The plats were separated by 2-foot alleys. Every fourth plat received basic slag, was not inoculated, and served as a check plat. Hairy vetch was planted on September 23, 1936, at the rate of 30 pounds per acre in rows 4 feet apart making four rows per plat. The seed were disinfected with mercuric chloride. The commercial inoculant was applied according to the directions of the manufacturer. Soil inoculant was applied in the drill at the rate of 500 pounds per acre. The seed were covered immediately after planting in order to prevent any possible injury from the sun.

On half of the plats the fertilizer was applied in the drill by hand and the inoculated seed were then droppped on top of the fertilizer and covered. On the soil-inoculated plats the fertilizer and seed were distributed in the same manner as above and the inoculated soil placed on top of the fertilizer and seed.

On the other half of the plats the fertilizer was mixed with the soil by running a plow in the rows before the seed were planted.

In order to determine growth, 100 representative plants were dug from each plat on Novemner 11, 1936, and on December 13, 1936. The number of nodules were counted, the tops and roots were separated and weighed after having been dried in the oven, and then were analyzed for total nitrogen. On February 10, 1937, 100 plants were dug from each plat and the same determinations made except the nodules were not counted. On March 10, 1937, and April 10, 1937, the same determinations were made on plants from an entire row from each plat.

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[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Authorized for publication by the Director. Received for publication November 25, 1938.

[2]Graduate Assistant and Associate Agronomist, respectively.

RESULTS AND DISCUSSION

A perfect stand was obtained on every plat at the beginning of the experiment. Thus, in no instance were reduced yields due to poor germination. Differences in the appearance of the vetch due to the various treatments were noticeable soon after the plants came up.

NODULATION AND GROWTH

The data in Table 1 show that in general there is some correlation between the number of nodules and growth. The inoculated plants possessed more nodules and were much larger and healthier than the uninoculated plants. The uninoculated plants were nodulated; however, the nodules were minute and the small growth of the plants indicated that the bacteria were inefficient in fixing nitrogen. This indicates that the presence of nodules is not a sure sign that the plants are properly inoculated.

When commercial culture was used, it was found (Table 2) that basic slag did not reduce the number of nodules or growth of the vetch when applied in contact with inoculated seed. Growth was approximately 20% less when the inoculated seed were planted in contact with superphosphate and triple superphosphate than when the fertilizer was mixed with the soil prior to planting (Figs. 1 and 2). This difference was very obvious throughout the test. The superphosphate or triple superphosphate coming in contact with the inoculant caused no significant reduction in the number of nodules. Dolomite partially reduced or counteracted the injury caused by the superphosphate coming in contact with the seed (Figs. 1 and 2). The best results were obtained with all fertilizers except basic slag when the fertilizer was mixed with the soil before planting. If the seed and fertilizers are to be mixed, basic slag or superphosphate mixed with dolomite should be used.

When soil inoculant was used in contact with superphosphate, the number of nodules and growth of the plants were greatly reduced. The plants grown on plats where the superphosphate was mixed with the soil and did not come in contact with the inoculant produced 158% more growth than those grown on plats where the soil inoculant came in contact with the superphosphate. Figs. 1 and 2 show the differences in these treatments on various dates.

Commercial inoculant proved to be superior to soil inoculant especially when the inoculated seed and fertilizer were in contact. The superphosphate, when placed in contact with the inoculant and seed, was much more injurious when soil inoculant was used than when commercial inoculant was used. Vetch fertilized with 400 pounds of superphosphate applied in contact with soil inoculant produced 5 pounds of nitrogen per acre, while vetch fertilized with the same amount of superphosphate applied in contact with seed inoculated with a commercial culture produced 40 pounds of nitrogen per acre. When superphosphate was mixed with the soil before the soil inoculant was added, 14 pounds of nitrogen per acre were produced as compared with 49 pounds when commercial inoculant was used in the same manner.

TABLE 1.—*The influence of inoculation, kind of fertilizer, and method of application of fertilizer on the dry weight of the plants and number of nodules of hairy vetch.**

Fertilizer†	Inoculation	Total dry weight of tops and roots of 100 plants, grams		Percentage of total dry weight in tops		Number of nodules per 100 plants	
		In contact	Mixed with the soil	In contact	Mixed with the soil	In contact	Mixed with the soil
Basic slag	None	8.8	12.3	49	50	97	150
None	None	6.3	6.4	40	46	4	7
None	Commercial	8.1	11.3	56	47	133	181
Basic slag	Commercial	15.6	24.5	58	50	373	362
Superphosphate	Commercial	17.5	31.0	65	66	558	550
Triple superphosphate	Commercial	14.0	22.5	64	59	457	557
Superphosphate, dolomite	Commercial	25.7	35.8	67	66	659	737
Triple superphosphate, dolomite	Commercial	18.4	28.1	60	60	658	576
Superphosphate, muriate	Commercial	23.1	41.0	53	52	797	700
Triple superphosphate, muriate	Commercial	19.9	28.1	62	60	484	433
Superphosphate, muriate, dolomite	Commercial	38.2	48.3	64	61	1,213	1,132
Triple superphosphate, muriate, dolomite	Commercial	23.1	33.0	59	62	732	693
Basic slag, muriate	Commercial	35.0	40.5	54	58	570	737
Superphosphate	Soil	7.3	25.7	38	54	100	613
None	Soil	9.1	10.5	50	45	194	290

*All figures are the averages of the first two harvests.
†Phosphate applied at the rate of 64 pounds of P_2O_5, dolomite 400 pounds, and muriate of potash 50 pounds per acre.

TABLE 2.—*The influence of inoculation, kind of fertilizer, and method of application of fertilizer on the dry weight and nitrogen content of hairy vetch plants.**

Fertilizer†	Inoculation	Total dry weight per acre of tops and roots, lbs.		Percentage total dry weight in tops		Nitrogen content of plants							
						Tops		Roots		Total per acre, lbs.		Percentage of total that was in the tops	
		In contact	Separated	In contact	Separated	In contact, %	Separated, %	In contact, %	Separated, %	In contact	Separated	In contact	Separated
Basic slag	None	583	643	67	67	3.2	3.3	2.0	2.0	16.2	20.0	76	71
None	None	60	60	57	63	2.4	2.5	1.7	2.0	1.3	1.4	66	68
None	Commercial	574	576	66	72	3.5	3.5	1.9	1.8	16.9	17.4	78	83
Basic slag	Commercial	1,556	1,499	66	70	3.8	3.4	1.3	1.6	45.6	43.2	85	83
Superphosphate	Commercial	1,175	1,440	82	83	3.7	3.7	2.2	2.2	40.4	49.4	89	89
Triple superphosphate	Commercial	1,415	1,792	82	86	3.5	3.7	2.5	2.3	46.7	62.1	87	90
Superphosphate, dolomite	Commercial	1,725	2,048	78	82	3.8	3.7	2.5	1.9	60.6	69.2	84	90
Triple superphosphate, dolomite	Commercial	1,490	1,988	83	82	3.4	3.9	2.1	2.1	46.3	70.4	85	89
Superphosphate, muriate	Commercial	1,734	1,887	82	86	3.8	3.9	2.3	2.6	61.4	70.5	88	90
Triple superphosphate, muriate	Commercial	1,481	1,764	86	85	3.6	3.4	2.1	2.3	50.2	57.1	91	90
Superphosphate, muriate, dolomite	Commercial	2,503	2,377	85	80	3.1	3.5	1.8	2.0	72.5	76.3	91	88
Triple superphosphate, muriate, dolomite	Commercial	2,058	2,252	80	85	3.6	3.7	1.8	2.0	66.7	77.9	89	91
Basic slag, muriate	Commercial	2,614	2,857	74	75	3.2	3.3	1.7	1.5	72.8	81.9	84	88
Superphosphate	Soil	193	499	62	75	3.0	3.1	2.0	2.3	5.0	14.3	71	81
None	Soil	491	533	73	72	3.1	3.0	2.3	2.0	14.0	14.5	79	80

*Harvested April 12, 1937.
†Phosphate applied at the rate of 64 pounds of P_2O_5, dolomite 400 pounds, and muriate of potash 50 pounds per acre.

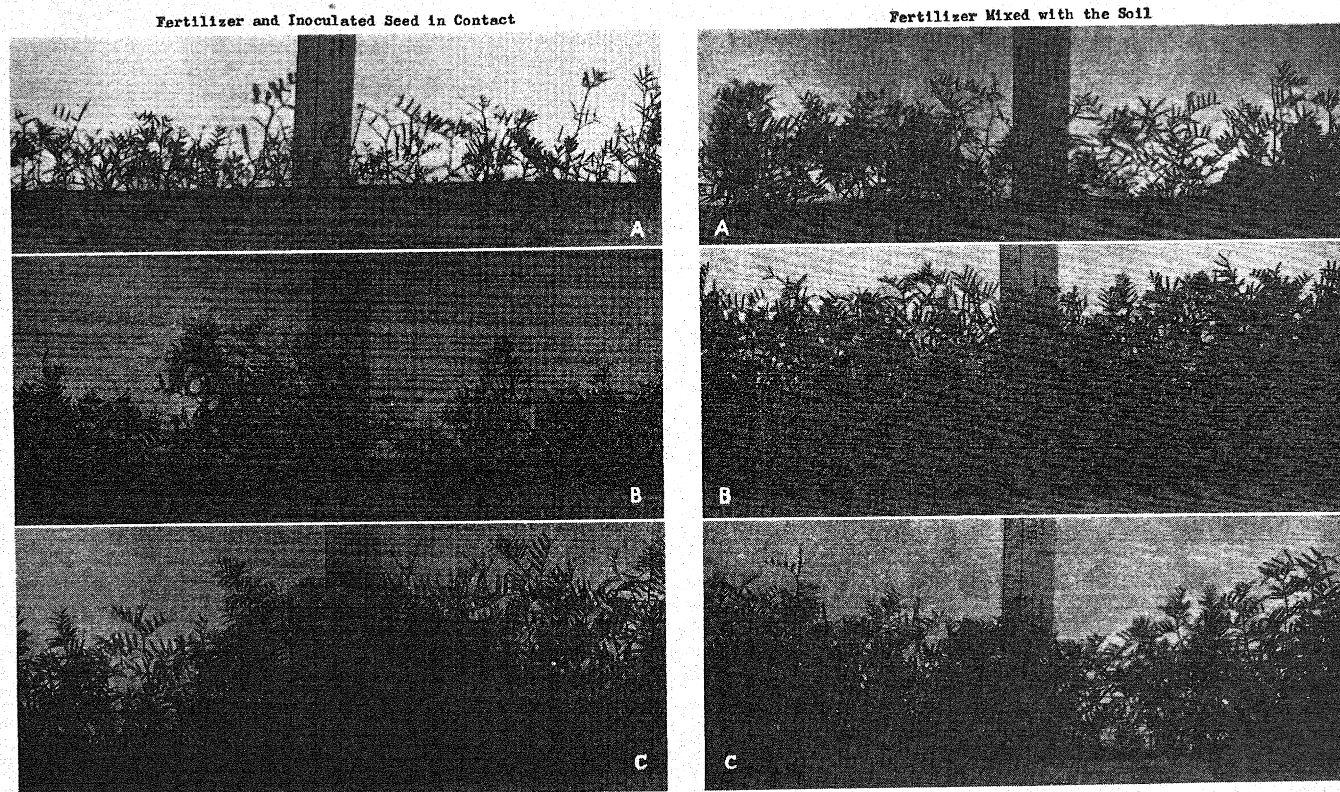

FIG. 1.—Vetch plants from different fertilizer and inoculation treatments, photographed November 10, 1936. A, superphosphate and soil inoculation; B, superphosphate and commercial inoculation; and C, superphosphate and dolomite and commercial inoculation.

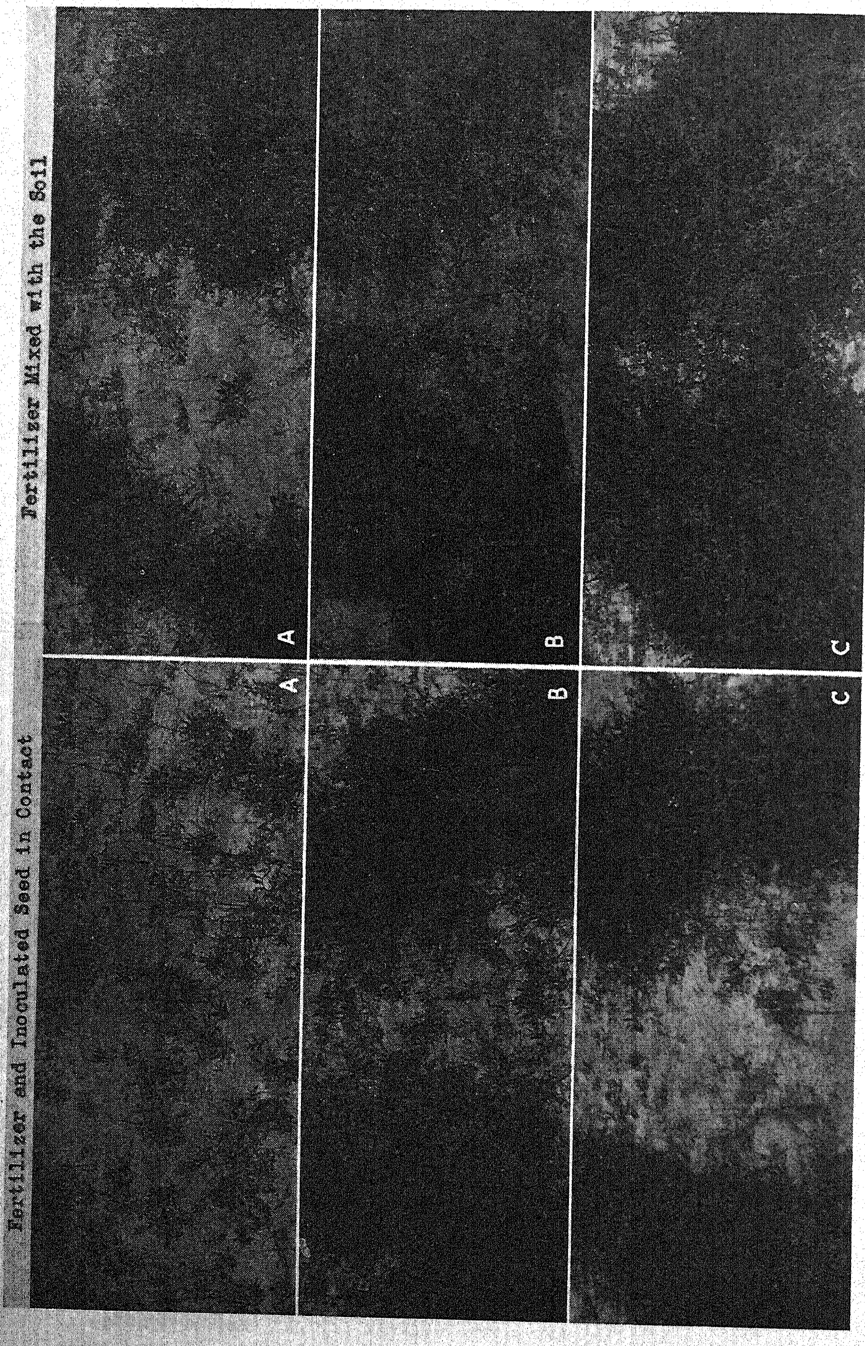

FIG. 2.—Vetch plants from different fertilizer and inoculation treatments, photographed April 12, 1937. A, superphosphate and soil inoculation; B, superphosphate and commercial inoculation; C, superphosphate and dolomite and commercial inoculation.

RATIO OF TOPS TO ROOTS

From Tables 1 and 2 it can be seen that the percentage of tops increased as the vetch grew older. In general, the treatments that produced the highest yields produced the highest ratio of tops to roots.

The plants grown on uninoculated plats, soil inoculated plats, and on unfertilized plats produced a lower percentage of tops than those grown on fertilized and commercially inoculated plats. The fertilizers stimulated top growth more than root growth.

NITROGEN CONTENT

The nitrogen content of tops and of roots, total nitrogen per acre, and percentage of total nitrogen in the tops on April 12 are reported in Table 2. The unfertilized, uninoculated plants produced practically no growth and had a very low percentage of nitrogen. The fertilized and uninoculated plants produced a small growth with a medium percentage of nitrogen. The inoculated and unfertilized plants had a higher percentage of nitrogen than plants that received fertilizer without inoculation; however, the plants from both treatments produced very little growth. To get maximum growth with maximum percentage of nitrogen, both fertilizer and inoculation were necessary.

The percentage of nitrogen in vetch can be increased by the proper fertilizer and inoculation treatment but there seems to be a point above which no increase could be made. The nitrogen is used to increase vegetative growth rather than to increase the percentage of nitrogen in the plant. The method of application of fertilizer did not have a very marked effect on the nitrogen content of the plants.

The tops of plants receiving fertilizer and commercial inoculant contained approximately 85 to 90% of the total nitrogen. These results show the importance of turning under the entire plant in soil building. Both commercial and soil inoculation without fertilizer produced tops containing approximately 80% of the total nitrogen. Fertilizer and no inoculation produced plants with tops containing approximately 75% of the total nitrogen. The plants with no inoculation and no fertilizer produced tops with about 67% of the total nitrogen.

The method of applying the fertilizer did not greatly affect the percentage of total nitrogen in the tops except in the superphosphate and soil inoculated treatment. Mixing superphosphate with the soil before adding the soil inoculant produced tops with 81% of the total nitrogen, while the tops on the plats where superphosphate and soil inoculant were applied together contained only 71% of the total nitrogen.

CONCLUSIONS

1. The presence of nodules on the roots of vetch was not a sure indication that the plants were properly inoculated.

2. Approximately 20% less growth was produced when superphosphate and triple superphosphate came in contact with seed inocu-

lated with a commercial culture than when the fertilizer was mixed with the soil prior to planting.

3. Growth was 158% more when superphosphate was mixed with the soil before adding soil inoculant than when the superphosphate came in contact with the soil inoculant.

4. Slag or equal amounts of dolomite and superphosphate did not seriously reduce the growth when applied in contact with the inoculated seed. Dolomite partially reduced or counteracted the injury caused by the superphosphate coming in contact with inoculated seed.

5. The percentage of nitrogen in the vetch plants was increased by applications of fertilizer or by inoculation. The highest percentage of nitrogen, as well as the largest amount of vegetative growth, was obtained when both fertilizer and inoculant were used.

6. The method of applying fertilizers did not affect the percentage of nitrogen in the vetch plants.

7. Commercial inoculant was only slightly better than soil inoculant when no fertilizer was used. When fertilizer was used, commercial inoculant was much superior to soil inoculant regardless of how the fertilizer was applied.

8. The ratio of tops to roots increased as the vetch grew older. The treatments that produced the highest yields of vetch produced the highest ratio of tops to roots.

9. Most of the nitrogen in vetch was in the tops.

LEGUME NODULE DEVELOPMENT IN RELATION TO AVAILABLE ENERGY SUPPLY[1]

FRANKLIN E. ALLISON AND C. A. LUDWIG[2]

THE causes of the variations in nodulation of legumes under more or less usual conditions of growth have been discussed by the writers in three previous papers (1, 2, 3).[3] Particular attention (3) was given to the situation where a decrease in nodulation occurs due to the presence of a liberal supply of combined nitrogen. The general conclusion arrived at was that normally under good cultural conditions the most important, but not the sole, factor in nodulation is the supply of available carbohydrate[4] reaching the nodules. In accord with this view the effect of fixed nitrogen was traced to the decrease in available carbohydrate in the roots caused by it. It was further pointed out (2) that under certain conditions, such as where ineffective bacterial strains are used or where the nitrogen hunger condition occurs, carbohydrate accumulates unless fixed nitrogen is supplied and is not the limiting factor in growth. Other investigators, particularly Fred and Wilson (5), have also emphasized the importance of carbohydrate supply in legume symbiosis. Recently several investigators have published additional data that in our judgment confirm our previous conclusions even though some of these authors regard the carbohydrate supply explanation as inadequate. One author (17, 18) has proposed a similar but distinct and more complicated explanation to take its place. It seems well at this time, therefore, to reexamine the adequacy of our original hypothesis in the light of the new experimental data and the objections that have been raised.

The newer experimental results, like the older ones, indicate that under ordinary growing conditions, where little or no fixed nitrogen is present in the growth medium, a close correlation exists between the quantity of carbohydrate photosynthesized, on the one hand, and the extent of nodulation and nitrogen fixation, on the other. Since in this case the major interrelations are well established and have not been questioned, little further discussion of the point is necessary. Attention will be given, however, to some of the points that have been given special consideration by recent investigators.

EFFECT OF FIXED NITROGEN ON ROOT CARBOHYDRATE AND NODULATION

Considerable new evidence has been presented that supports our previous statements (1, 2, 3) to the effect that additions of fixed

[1]Contribution from the Fertilizer Research Division, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture. Received for publication December 3, 1938.

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The authors are greatly indebted to Dr. Dean Burk and Mr. Francis Minor, both of this laboratory, for many helpful suggestions given during the preparation of this manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 157.

[4]The term carbohydrate is meant to include all metabolizable carbon compounds not containing nitrogen, chiefly sugars and starches, but also some organic compounds usually present in small percentages.

nitrogen that decrease nodulation also decrease the carbohydrate supply to the roots. Thus, Fred and Wilson (5) and Orcutt and Wilson (11) have shown that at nitrate concentrations sufficient to decrease the number and size of nodules there occurs a decrease in concentration of soluble sugars in the plant sap. Georgi (7), as well as Fred and Wilson, has shown also that this decrease in nodulation is partially overcome by supplying additional carbon dioxide to the leaves, a treatment that increases the sugar concentration in the tops and roots. The results of Hopkins (8) show in a general way that a high level of soluble nitrogen commonly causes a lower sugar concentration and reduced nodulation. Data in two of these papers show clearly the pronounced sugar concentration gradient, decreasing from the top to the root, to which we made previous reference (2, 3).

Other recent work gives definite, though indirect, evidence of the importance of carbohydrate supply in the phenomenon under discussion. Thornton and Nicol (14) have observed that with increasing nitrate both nodule numbers and volume of bacterial tissue per unit mass of root fall off rapidly. In expèriments by Thornton (13), nitrate did not inhibit the production of the root-curling substance by the bacteria but did interfere with its action, except where sugar was added. He states that "these results support the view that the effect of nitrate is casually connected with a reduction in the carbohydrate available to the plant roots or at any rate with the ratio of these carbohydrates to nitrate". Thornton and Rudorf (15) have observed a thickening and suberization of the lateral endodermis of the nodule, similar to wound isolation, following nitrate applications. Changes in the nodule tissue and the prevalence of coccus forms, suggestive of starvation, also occurred.

In spite of these evidences of starvation, Thornton and Rudorf (15) decided tentatively that the nodules suffered from a misuse rather than from a lack of carbohydrate, since the formation of cell wall thickenings indicated to them the presence of carbohydrate in not inconsiderable quantities. We believe, nevertheless, that the starvation explanation is to be regarded as the more plausible one and that the observations of these workers, together with others of Thornton (13), merely show in some detail the mechanism of the response of the host plant and bacteria to the decrease in carbohydrate. Justification for this interpretation may be had from still other work by Thornton (12) in which he observed that the morphological appearance of carbohydrate-starved nodules on plants placed in the dark did not differ greatly from that of nodules grown with abundant fixed nitrogen. In the dark the cell wall thickenings were not observed, but their formation was hardly to be expected since obviously carbohydrate starvation induced by darkness is attained much more rapidly, and is more extreme than if produced by additions of fixed nitrogen. Most published results (14), in fact, do not show absolute absence of nodule growth even at rather high concentrations of fixed nitrogen; and if the carbohydrate is adequate for some nodule growth, it must be adequate for the formation of wall thickenings, whatever may be the stimulus leading to their formation. Hence, the presence of a certain amount of carbohydrate in nodules on plants supplied abundant combined nitrogen is really not surprising but is to be expected.

Georgi (7) observed that the addition of combined nitrogen caused a definite decrease in the concentration of sugar in the plant sap but a relatively greater decrease in the development of nodule tissue. His data and conclusions are considered in some detail in the section that follows.

NODULE FORMATION AND SUGAR CONCENTRATION

Georgi (7) and a few other workers who have recently considered the subject appear to have supposed that the carbohydrate supply hypothesis implies that a linear relation should exist between sugar concentration in the root sap and nodules produced, although we tried (2, pages 124 to 127; 3, page 437) to guard against the possibility of such an interpretation. We emphasized that wide variations in the growth of plants over extended periods of time are *not* accompanied by correspondingly wide variations in the concentration of soluble sugars in the plant sap. The sugar concentration in inoculated legumes (or non-legumes) is ordinarily neither exceedingly low nor exceedingly high. If carbohydrate production falls off, plant activities are curtailed and the available supply is used largely for respiration. If, on the other hand, carbohydrate synthesis is accelerated, protein synthesis and plant growth are also accelerated, so that during a considerable growth period carbohydrate concentration does not change nearly as much as the dry weights of plants and of nodules. Hence, in the presence of added fixed nitrogen, it is not to be expected that a large decrease in nodulation will be accompanied by a correspondingly large decrease in sugar concentration.

The carbohydrate supply hypothesis says that over a given growth period during which conditions are about normal the amount of nodule tissue produced will be roughly proportional to the amount of carbohydrate delivered to the site of the nodules. It says nothing directly about the effect on nodule production of concentration of carbohydrate in the root sap but does imply, of course, that an orderly relationship between them exists. This relationship depends on the effect which concentration has on the rate of transport of carbohydrate to the nodules. What this effect is, except qualitatively, is apparently unknown. It appears to us, therefore, that Georgi's data are insufficient for testing the carbohydrate supply hypothesis since it is impossible to determine quantitatively from concentration data the amount of nodule tissue to expect on the basis of the hypothesis.

However, if it be assumed that the rate of transport of carbohydrate is directly proportional to its concentration in the root sap, and it is possible that transport may be an increasing rather than a linear function of concentration, it can be shown mathematically that on the basis of the carbohydrate supply hypothesis nodule production will increase approximately exponentially with increase in carbohydrate concentration. In other words, if the sugar concentration is increased two-fold and maintained at this higher level, the *rate* of plant growth and nodule production will also be increased only about two-fold, but the increases in *total dry weights* of both the plant and nodules will be increased several-fold after a considerable growth

period. There are, of course, a large number of reasons well known to students of plant physiology why a close correspondence of observed values with calculated ones might not occur, but the conditions which would lead to so great a departure as to produce a linear instead of an exponential relation would be very much unexpected. Hence, while the relation might not be strictly exponential, it could hardly be other than some kind of increasing one under usual conditions. In spite of the fact that we do not consider Georgi's data pertinent as a test of the carbohydrate supply hypothesis, we calculated, on the assumptions mentioned above, the number of nodules to be expected on some of his high carbohydrate plants. The numbers obtained by calculation were greater than the numbers observed rather than less, as he concluded. If nodule weights had been given rather than numbers, it is likely that the agreement would have been better, since nodule weight usually increases more rapidly than nodule numbers.

We may conclude, therefore, that it follows from the carbohydrate supply hypothesis that any factor which increases the sugar concentration level in the plant and maintains it at this new level during a considerable growth period, should produce a much greater effect on the weight of nodules formed during the period.

EFFECT OF FIXED NITROGEN ON RELATIVE GROWTH OF PLANT PARTS

In a previous (3) publication we pointed out that applications of fixed nitrogen that are sufficient to cause a marked reduction in nodulation also cause a markedly increased growth of the tops and a relatively smaller growth of the roots. We attributed the decreases in the growth of both the nodules and the roots to the same cause, namely, lack of carbohydrate. Wilson (18, pages 23 to 29) apparently misunderstood our views and as a result criticized our paper at some length. His understanding appears to have been that we advanced a theory that a high top-root ratio (abundant top growth at the expense of root development) is the cause of reduced nodulation on legumes given abundant fixed nitrogen. However, while we discussed top-root ratios at some length, we did so only as evidence that fixed nitrogen decreases the carbohydrate supply to the roots by increasing carbohydrate utilization in the tops. We concluded that "decreased nodulation in the presence of soluble nitrogenous salts is due to inadequate carbohydrate supply in the roots". Our position has always been in harmony with his concluding statement that "it appears more probable that the two phenomena" (increased top-root ratio and decreased nodulation) "are connected through a common cause— than that they stand in a cause and effect relation". A detailed consideration of his criticisms would appear to be unnecessary.

In view of Wilson's misunderstanding it seems desirable, however, to restate in part our position regarding top-root ratio in the hope that certain points will be made clearer. We have never stated, nor meant to imply, that any and every condition that causes a wide top-root ratio will cause a relatively small growth of nodules. We con-

sidered *only* the situation where the wide ratio results from the poor growth of roots relative to tops due to deficient root carbohydrate. We have repeatedly stressed the marked difference in carbohydrate supply to the roots and nodules where the plant relies largely or wholly on atmospheric nitrogen in contrast to the conditions where nitrogenous fertilizers are added in abundance. *When fixed nitrogen is not supplied*, the carbohydrate supply to the roots is average or slightly above average, and the total dry weight of the plant, dry weight of nodules, and nitrogen fixed are ordinarily in rough proportion to carbohydrate synthesis. Under these conditions of adequate root carbohydrate, nodules do not necessarily occur proportionally to roots or inversely to top-root ratio when some special factor radically affects nodulation, root growth, or top-root ratio. We consider Wilson in error in assuming that we implied otherwise. *When fixed nitrogen is supplied*, which is the only condition considered by us (3), the situation is very different; root carbohydrate is limited and both nodule and root growth as compared with top growth are depressed somewhat similarly, and for the same reason. While the carbohydrate supply hypothesis attributes this last-named effect to the lowered carbohydrate level, it does not exclude the operation of other influences on top-root ratio or on nodule growth, such as temperature, soil acidity, moisture, aeration, mineral supply, and photoperiodism, especially when the factor is varied to a marked degree.

Thornton (13) and Thornton and Nicol (14) consider that the occasional failure of nodule growth to parallel root growth is a serious objection to the views which we expressed. This does not follow, however, because, as pointed out previously (2, pages 124 to 127; 3, page 437), nodule development is more sensitive to low carbohydrate supply than is root growth, as might be expected. Sometimes, under conditions of low carbohydrate, considerable root growth may occur with little or even no nodule formation, provided, of course, that enough combined nitrogen is present or being fixed to permit the root growth. This occurs often with plants grown in the greenhouse in the winter.

THE NITROGEN HUNGER CONDITION

When the initiation of nitrogen fixation is delayed in young seedlings that are photosynthesizing rapidly and are not supplied with combined nitrogen, carbohydrate accumulates in excess and the plants undergo a nitrogen hunger condition. Reference was made to this special case previously (2). This condition manifests itself after the nitrogen reserves of the seed are exhausted and *before* the nitrogen-fixing process starts functioning. When fixation starts, the rate is frequently extremely rapid until the accumulated excess carbohydrate has been reduced to normal.

This hunger condition is usually overcome after about one week, or occasionally longer, without special treatment, and in spite of the ever-increasing accumulation of carbohydrate and ever-widening carbohydrate-nitrogen ratio up to, if not a little beyond, the time of the initiation of the nitrogen fixation process. This is well illustrated

by the data of Rüffer which have been plotted by Wilson (18, page 21). In experiment 1 of Rüffer's data the total carbohydrate-total nitrogen ratio was about 5:1 when the hunger period started, about 17:1 when nitrogen fixation started, and rapidly decreased after reaching a value of 19:1.

Normal symbiosis may sometimes be hastened by the addition of a little combined nitrogen or by shading for a few days. Orcutt and Fred (10) and Fred, Wilson, and Wyss (6) have recently supplied additional data on this point. Orcutt and Fred (10) conclude that "an extremely high carbon-nitrogen ratio in the plant inhibits nitrogen fixation". Fred, Wilson, and Wyss (6) and Wilson (18) arrive at essentially the same conclusion although stated less definitely. However, we can see no clear evidence that the hunger condition is caused specifically by a wide carbohydrate-nitrogen ratio or "relation", although obviously a high ratio accompanies it. High carbohydrate and low nitrogen also accompany it, and its cause might be either of these three things. And, again, the cause may well be neither. On the basis of our present information, particularly with regard to the effect of added fixed nitrogen in bringing it to a close, it seems to us that of the three possibilities mentioned it is more likely that the hunger condition is due directly to lack of sufficient nitrogen for the building up of normal nodule tissue, for adequate enzyme production, and for the proper functioning of the cells in which nitrogen fixation can occur, than to either excess carbohydrate or high carbohydrate-nitrogen ratio.

On the basis of present information and in agreement with our previous views it appears, therefore, that the existence of a nitrogen hunger condition has little bearing on the carbohydrate hypothesis and certainly no more than on the carbohydrate-nitrogen relation hypothesis discussed below. The carbohydrate hypothesis, as we have repeatedly stated, obviously cannot account for every variation in nodulation and nitrogen fixation that occurs in legumes, but applies only under reasonably normal conditions. When some factor other than carbohydrate, such as very inadequate calcium or phosphorus, poor bacterial strains, or even lack of initial nitrogen, prevents normal growth and fixation under good photosynthetic conditions, carbohydrate must accumulate and temporarily, at least, become a secondary factor in legume symbiosis. This appears to be what happens in the nitrogen hunger condition.

THE CARBOHYDRATE-NITROGEN RELATION HYPOTHESIS

Wilson, who originally (5) favored a carbohydrate supply hypothesis similar to or identical with ours, later (17) decided that it was too limited in its implications and presented a carbohydrate-nitrogen relation hypothesis as a substitute. He (18) presented evidence which indicated to him that "a given carbohydrate-nitrogen balance in the plant will condition a more or less specific response in—number, size, and distribution of the nodules; quantity of nitrogen fixed; onset and duration of the nitrogen hunger stage; and response to light, fixed nitrogen, and other environmental conditions." He defined (18,

page 4) carbohydrate-nitrogen relation or balance, in varying ways involving ratios between soluble or total carbohydrate and soluble or total nitrogen. He set down no very specific rules for judging just which relation is the governing one under any given condition. In part because of this indefiniteness, or failure to be more specific, the hypothesis seems to us to be somewhat intangible and involved. In support of his ideas regarding the importance of the carbohydrate-nitrogen relation Wilson (18) cited data from numerous experiments; but these do not show either that the carbohydrate-nitrogen relation is, or that the carbohydrate supply is not, the factor governing nodulation. Indeed, they can be used to show the importance of carbohydrate supply equally or more reasonably than to show the importance of the "relation".

The relation or ratio may be, and very likely is, merely a resultant and without governing or causative significance. Certainly definite correlations can exist in the complete absence of any causative or regulating relation. By way of illustration let us consider the case of legumes grown under ideal growth conditions except for an inadequate supply of phosphorus. Now, with increasing additions of phosphorus, there will occur increased plant growth, nodulation, and nitrogen fixation. Accompanying these increases there will undoubtedly be a narrowing of the carbohydrate-phosphorus and probably also of the nitrogen-phosphorus ratio. The increased plant growth, nodulation, and nitrogen fixation would be correlated with these decreased ratios, but the significance of the correlations would be negligible since it is obvious that under the conditions mentioned the controlling factor is phosphorus alone. Correlation does not, therefore, prove significance or causality, particularly where the correlation is with a relation or ratio rather than with a single varying factor. This idea has been frequently stressed by many writers. For instance, Went and Thimann (16, page 9), in discussing plant hormones, state that while "experiments show that there is a parallelism between a given carbon-nitrogen ratio and a given type of growth, no causal relation has been shown to exist". In the present instance atmospheric nitrogen cannot be fixed by legumes until adequate carbohydrate is present. The correlation appears to us, therefore, to be more reasonably explainable on the basis that nodulation and carbohydrate-nitrogen relation are both dependent on carbohydrate supply, which is the independent controlling factor. Until new experimental results are presented which show that there is no adequate, reasonably direct relation between carbohydrate supply and nodulation in legumes growing under normal conditions and fixing nitrogen, there is clearly no need for a substitute for the carbohydrate supply hypothesis.

As mentioned above, Wilson rejected the carbohydrate hypothesis because he considered it too limited in its implications. Most of these supposed limitations have been discussed above and shown not to exist. But even if we should assume some of them to be real it is difficult to see wherein his hypothesis is any less limited in its implications. According to Wilson's hypothesis, nodulation, etc., increase as the carbohydrate-nitrogen relation widens so long as it does not become too wide. Above this critical point a further widening produces a

reversal or harmful effect (18, page 12). This reversal of the effect, together with the fact that there is no very strong evidence that the carbohydrate-nitrogen relation in itself ever governs or controls nodulation, seems to us to indicate that the hypothesis rests upon a decidedly insecure basis. On the other hand, according to the carbohydrate supply hypothesis, nodulation, etc., normally increase indefinitely with increase in carbohydrate supply. However, if some other factor essential for growth or nitrogen fixation (or both) becomes very limiting and prevents or greatly retards these processes, the carbohydrate may, of course, accumulate if photosynthesis is active. Although the carbohydrate supply is normally the limiting and hence the controlling factor in nodulation, it is not always so, as we have repeatedly stated. It would be surprising, indeed, if it were. Furthermore, if it should be proved in the future, that an accumulation of carbohydrate is directly responsible for poor nodule development and limited nitrogen fixation rather than the resultant of it as the evidence now indicates, such a development would merely necessitate a corresponding change in the hypothesis. It would not necessitate any substitution of carbohydrate-nitrogen relation for carbohydrate supply. Such a modification would only put our hypothesis on a basis comparable with that of Wilson's since he now says that nodulation increases as the relation widens so long as it does not become too wide. We are unable to see, therefore, that the carbohydrate-nitrogen relation hypothesis is any less limited in its implications than the simpler carbohydrate supply hypothesis which he wishes to displace.

In this connection it is interesting to note that Nightingale (9, pages 154 to 155), as part of a long review, has recently expressed the opinion that the cause of the various responses of plants to the carbon-nitrogen ratio, recorded many times in recent literature, is usually either carbohydrate lack or nitrogen lack, depending upon which is in minimum. It would seem that this statement applies to the case under discussion. Where active nitrogen fixation is proceeding, either by free-living or symbiotic organisms, it should be remembered that carbohydrate is necessarily in minimum since the supply of atmospheric nitrogen is in this case available and inexhaustible. Hence growth is roughly proportional to carbohydrate supply. This proportionality, so obvious in the case of a one-celled organism such as Azotobacter, is less obvious in the case of legumes only because the system is so much more complicated. Of course where nitrogen fixation for some reason cannot occur, carbohydrate may accumulate and is not the controlling factor. Our insistence on the preponderating importance of carbohydrate supply under usual conditions does not mean that we think no other independent influences are at work, but rather that such influences are usually relatively unimportant.

Finally, then, it seems to us that the data published since the appearance of our former papers are remarkably consistent in indicating the correctness of the hypothesis which we set forth and that criticisms of it have had their origin in a misapprehension of the hypothesis itself or of its implications.

SUMMARY

Consideration of recently published data and interpretations bearing on carbohydrate supply as applied to legume symbiosis seems to justify the following conclusions:

1. Although there are many special factors which independently influence nodule behavior, the amount or supply of available carbohydrate reaching the roots is normally the chief influence that affects nodulation under variations in photosynthesis and in the presence of either free nitrogen or varying quantities of combined nitrogen. Where nitrogen assimilation is not occurring, as in the nitrogen hunger condition, nitrogen is present in minimum and carbohydrate is not the controlling factor.

2. The inhibiting effect on nodulation of large additions of fixed nitrogen is due chiefly to the resultant lowering of the available carbohydrate supply. Root growth relative to top growth is also lowered for the same reason.

3. A small change in sugar concentration in the root sap may produce a change in mass of nodules several times as large during a considerable growth period because the weight of nodules, like the total dry weight of the plant, tends to increase exponentially.

4. The carbohydrate supply hypothesis accounts for varying degrees of nodulation under different growth conditions more simply, directly, and adequately than the subsequently proposed carbohydrate-nitrogen relation hypothesis.

LITERATURE CITED

1. ALLISON, FRANKLIN E. Importance of carbohydrate supply in legume symbiosis. Nature, 134:144. 1934.
2. ———. Carbohydrate supply as a primary factor in legume symbiosis. Soil Science, 39:123–143. 1935.
3. ———, and LUDWIG, C. A. The cause of decreased nodule formation on legumes supplied with abundant combined nitrogen. Soil Science, 37: 431–443. 1934.
4. BOND, GEORGE. Quantitative observations on the fixation and transfer of nitrogen in the Soya bean, with especial reference to the mechanism of transfer of fixed nitrogen from bacillus to host. Ann. Bot., 50:559–578. 1936.
5. FRED, E. B., and WILSON, P. W. On photosynthesis and free nitrogen assimilation by leguminous plants. Proc. Nat. Acad. Sci., 20:403–409. 1934.
6. ———, ———, and WYSS, ORVILLE. Light intensity and the nitrogen hunger period in the Manchu soybean. Proc. Nat. Acad. Sci., 24:46–52. 1938.
7. GEORGI, CARL E. Influence of the carbohydrate-nitrogen relation on nodule production by red clover. Jour. Agr. Res., 51:597–612. 1935.
8. HOPKINS, E. W. The effect of long and short day and shading on nodule development and composition of the soybean. Soil Science 39:297–321. 1935.
9. NIGHTINGALE, GORDON T. The nitrogen nutrition of green plants. Bot. Rev., 3:85–174. 1937.
10. ORCUTT, FRED S., and FRED, E. B. Light intensity as an inhibiting factor in the fixation of atmospheric nitrogen by Manchu soybeans. Jour. Amer. Soc. Agron., 27:550–558. 1935.
11. ———, and WILSON, P. W. The effect of nitrate-nitrogen on the carbohydrate metabolism of inoculated soybeans. Soil Science 39:289–296. 1935.
12. THORNTON, H. G. The influence of the host plant in inducing parasitism in lucerne and clover nodules. Proc. Roy. Soc., B 106:110–122. 1930.

13. ———. The action of sodium nitrate upon the infection of lucerne root-hairs by nodule bacteria. Proc. Roy. Soc., B 119:474–492. 1936.
14. ———, and NICOL, HUGH. Reduction of nodule numbers and growth, produced by the addition of sodium nitrate to lucerne in sand culture. Jour. Agr. Sci., 26:173–188. 1936.
15. ———, and RUDORF, J. E. The abnormal structure induced in nodules on lucerne (*Medicago sativa* L.) by the supply of sodium nitrate to the host plant. Proc. Roy. Soc., B 120:240–252. 1936.
16. WENT, F. W., and THIMANN, K. V. Phytohormones. New York: Macmillan Co. 1937.
17. WILSON, P. W. The carbohydrate-nitrogen relationship in symbiotic nitrogen fixation. Jour. Bact., 29:82. 1935.
18. ———. The carbohydrate-nitrogen relation in symbiotic nitrogen fixation. Wis. Agr. Exp. Sta. Res. Bul. 129:1–40. 1935.
19. ———, and UMBREIT, W. W. Fixation and transfer of nitrogen in the soybean. Zentbl. Bakt. etc., II. Abt., 96:402–411. 1937.

A RELATIONSHIP BETWEEN POLLINATION AND NODULATION OF THE LEGUMINOSEAE[1]

J. K. WILSON[2]

THE occurrence of root nodules on legumes was recorded nearly 500 years ago, but not until 1858 did Lochmann report that nodules do not form on all legumes. Since that date several non-nodulating legumes have been found by various investigators. Only a few of the many species of legumes have been carefully examined in this regard and it should be expected therefore that others will be added to the list.

While studying the leguminous plants and their associated organisms, it was observed that certain species appeared to symbiose as measured by nodulation with strains of the rhizobia whose morphological and physiological characters were almost identical, while other species appeared to symbiose with a large number of diverse strains whose morphological and physiological characters were extremely dissimilar. Thus, there appear to be recognizable at least three divisions of the legumes as related to nodulation, namely, the non-nodulating legumes, those that symbiose with strains nearly alike, and those that symbiose with dissimilar strains of the organism. These divisions appear to merge from one into the other so gradually that sharp demarkations are difficult to make.

All the previous research on the nodulation of legumes includes species of about 40 genera, of which there are about 500, and of only a few of the comparatively large number of strains of the rhizobia. Thus, a more complete list of the symbionts as regards their relationship to each other is needed. From the information available it appears that at one extreme the non-nodulating plants are found and at the other those legumes that nodulate with a large number of strains of the rhizobia, and that an uneven gradation of species from one condition to the other is found between these extremes.

Attempts have been made to explain why plants symbiose with one strain and not with another or not at all with any strain. Apparently no satisfactory explanation exists. The root nodule organisms were divided by Mazé (7)[3] into two groups. One group symbiosed with plants that grew on alkaline soil and the other with plants that grew on acid soil. The limiting hydrogen-ion concentration for the growth of the organisms was roughly correlated by Fred and Davenport (3) with the acidity of the juice expressed from the corresponding plants. A correlation between the protein constitution of the seeds and the specific *Rhizobium* with which the species will symbiose was offered by Baldwin, Fred, and Hastings (1), while Süchting (12) held that the bacteria produce a "toxin" which stimulates the plant to produce an antibody, and that the relationship between these two

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication December 8, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 169.

substances determines whether symbiosis occurs. McDougall (8) suggested that the unusually thick-walled and lignified root hairs of certain non-nodulating plants prevent the symbiosis.

When plantlets are produced from sterile seed and grown in closed containers to the exclusion of all but one strain of the rhizobia, perhaps 1, 10, 50, or 100% of the plants will bear nodules. Such plants as do bear nodules may be several times as large as, and possess a greener color than, those that do not bear nodules. Since all plants grew under the same conditions of nutrition, light, moisture, and temperature, and were exposed to just one strain of *Rhizobium*, it is suggested that those plants which did bear nodules were in some way inherently different from those that did not bear nodules. If this were true, the factors that make them different might appear through a mixing of characters by cross-fertilization. When plants are self-pollinated for a few generations they tend to become homozygous and are considered to be heterozygous only when cross-pollination occurs, although it is possible to have a heterozygous plant that will self. In numerous cases selfing or crossing will occur depending on the source of the pollen that effects fertilization. Thus the extent of cross-pollination or of selfing should influence in the offspring the number of factors permitting nodulation. An effort is made in this paper, therefore, to point out a relationship that may exist between the extent of selfing or crossing and the non-occurrence or occurrence of nodules on legumes.

STRAINS OF RHIZOBIUM EMPLOYED

In this work an effort was made to obtain one or more strains representing most of the plant bacteria group proposed by previous workers. These strains were isolated from the following legumes: *Albizzia julibrissin*, *Amorpha fruticosa*, *Amphicarpa monoica*, *Apios tuberosa*, *Baptisia australis*, *Caragana frutescens*, *Cassia chamaecrista*, *Cicer arietenum*,[4] *Crotalaria spectabilis*, *Dalea alopecuroides*, *Desmodium canadensis*, *Glycene max*, *Laburnum vulgare*, *Lens esculenta*, *Lespedeza striata*, *Lotus corniculatus*, *Lupinus perennis*, *Medicago sativa*, *Onobrychis viciaefolia*, *Oxytropus lambertii*, *Phaseolus vulgaris*, *Robinia pseudo-acacia*, *Sesbania macrocarpa*, *Spartium scoparium*, *Stizolobium deeringianum*, *Strophostyles helvolus*, *Swainsonia coronillafolia*, *Thermopsis caroliniana*, *Trifolium pratense*, *Vicia villosa*, *Vicia villosa* var. Gore, *Vigna sinensis*, and *Wistaria chinensis*.

PRESENTATION OF DATA

In Table 1 the relationship between pollination and nodulation by many strains of the rhizobia is indicated. The species of legumes at the beginning of the list in bracket 0, which are indicated as being completely self-pollinating, do not symbiose as measured by the occurrence of nodules with any known strain of *Rhizobium*. As the list is extended the species symbiose with one or more of the strains, until at the end, where cross-pollination is obligatory, they symbiose with 30 of the 32 strains. For instance those species opposite 0 in the

[4]Used only on *Cicer*.

table apparently symbiose with no known strain of *Rhizobium* with one or two possible exceptions. Those opposite bracket 1 were tested and found to symbiose with only one strain, while those species opposite bracket 30 were observed to symbiose with 30 strains.

If plants are self-pollinating, they should produce seed when covered with bags of cheesecloth to keep the insects away. This

TABLE 1.—*Nature of pollination as related to nodulation.**

	Species of legume	Nature of pollination
0	*Cercis canadensis* L.	Completely self-pollinating
	Cercis siliquastrium (L) Koch	
	Gymnocladus dioica (L) Koch	
	Gleditsia triacanthos L.	
	Cladrastis lutea (Michx. f.) Koch	
	Rynchosia phaseoloides	
	Parkinsonia aculeata L.	
	Bauhinia purpurea L.	
	Ceratonia siliqua L.	
	Acacia baileyana F. Muell.†	
	Cassia 11 sp.†	
1	*Cicer arietenum* L.	Progressing from self-pollination toward cross pollination ↓
	Ulex europaens L.	
	Dorycnium herbaceum Vill.	
	Ornithopus sativus Bort.	
	Pueraria phaseoloides Benth.	
	Psoralea onobrychis Nutt.‡	
	Hippocrepis sp.	
2	*Lotus tetragonolobus* L.	
	Wistaria frutiescens Rafin	
	Indigofera langebergensis L. Bolus	
	Stizolobium deeringianum Bort.	
	Phaseolus aconitifolius Jacq.	
	Phaseolus angularis W. F. Wight	
	Lupinis perennis L.	
3	*Clitoria ternabea* L.	
	Laburnum anagyroides Medic.	
	Pithecolobium dulce Benth.	
	Albizzia lebbeck Benth.	
	Crotalaria verrucosa L.	
	Thermopsis fabacea DC.	
	Baptisia tinctoria R. Br.	
	Laburnum vulgaris Gris.	
	Clitoria sp.	
	Caragana frutescens DC.	
	Coronilla glauca L.	
	Vicia cracca L.	
	Vicia pratense	
	Lathyris pictensis	
	Trifolium pannonicum Jacq.	
	Canivalia ensiformis DC.	
	Ononis columnae All.	
	Platylobium obtusangulum Hook.	

*Figures at the left of the brackets indicate the number of strains of *Rhizobium* out of 32 which have been observed to symbiose with the species of legumes to the right of the bracket.

†Partly taken from the literature.

‡*Psoralea* in brackets 1 and 8 represent two lots of seed.

TABLE I.—*Continued.*

	Species of legume	Nature of pollination
4	*Ononis columnae* All.	Progressing from self-pollination toward cross pollination ↓
	Centrosema pubescens Benth.	
	Minosa invisa Mart.	
	Tephrosia nictiflora Boj.	
	Bolusanthus speciosus Harms	
	Daubentonia drummondii Rydb.	
	Crotalaria anagyroides H.B.K.	
	Lonchocarpa discolor Huber.	
	Bolusanthus speciosus Harms	
	Virgilia capensis Lam.	
	Tephrosia vogelii Hook.	
	Vicia faba L.	
	Vicia floridana S. Wats.	
	Lathyrus odoratus L.	
	Dichrostachy nutans Benth.	
	Pisum sativum L.	
5	*Trifolium dubium* Sibth.	
	Psoralea acualis Stev.	
	Caragana pekensis Kom.	
	Coronilla varia L.	
	Trifolium incarnatum L.	
	Lespedeza violaceae Maxim.	
	Strophostyles helvolus Torr. et Gray	
	Desmodium grandiflora (Walt) DC.	
6	*Astragalus falcata* Lam.	
	Crotalaria retusa L.	
	Vicia villosa Roth var. gore	
	Amphicarpa monoica (L) Ell.	
	Indigofera sp.	
	Phaseolus aurens Roxb.	
	Phaseolus lunatus (L)	
	Indigofera Sp.	
	Sutherlandia frutescens R. Br.	
	Desmanthus illinoiensis (Michx) MacM.	
7	*Mimosa pudica* L.	
	Ononis arvensis Linn.	
	Trifolium repens L.	
	Astragalus brachycarpus Bieb.	
	Astragalus mongolicus Bunge	
	Lespedeza fruticosa (L) Britton	
	Vicia villosa Roth.	
	Cyamopsis tetragonoloba (I) Taub.	
8	*Genista tinctoria* L.	
	Crotalaria mysorensis Roth.	
	Trifolium alexandrianum L.	
	Petalestemon villosum Nutt	
	Tephrosia virginiana (L) Pers.	
	Trifolium fragiferum L.	
	Cyamopsis tetragonoloba (L) Taub	
	Lespedeza hirta (L) Hornem.	
	Vicia pannonicum Jacq.	
	Amphicarpa pitcherii T. & G.	
	Psoralea onobrichis Bort.	

TABLE I.—*Continued.*

	Species of legume	Nature of pollination
	Leucanea glauca Benth.	
	Crotalaria spectabilis Roth.	Progressing from self-pollination toward cross pollination
	Laburnum alpinum Gris	
	Swainsonia coronillafolia Salisb.	
	Coronilla linnearus	
	Lespedeza striata Hook et. Arn.	
9	*Glycine max* (L) Merr.	
	Albizzia falcata Backer	
	Baptisia australis R. Br.	
	Spartium scoparium L.	
	Indigofera tinctoria L.	
	Petalestemon purpurea (Vent.) Rydb.	
	Colutea cilicica Bois & Bal.	
	Sutherlandia sp.	
10	*Lourea vespentilonis* Desv.	
	Trifolium suaveolens Willd.	
	Astragalus hornii A. Gray	
	Melilotus officinalis (L) Lam.	
	Melilotus alba Devr.	
	Crotalaria striata DC.	
	Trifolium agrarium L.	
	Psoralea esculenta Pursh.	
11	*Parosella aurea* Macbride	
	Galega afficinalis L.	
	Donia damperi	
	Astragalus alpinus L.	
	Vigna sinensis (L) Endl.	
	Tephrosia grandiflora Pers. Syn.	
	Genista supranubia Spach.	
	Crotalaria usaramoensis Baker	
12	*Trigonella caerulea* Ser.	
	Robinia kelseyii Hort.	
	Prosopis juliflora DC.	
	Lespedeza formosa	
	Albizzia julibrissin Biov (Durazzini)	
	Acacia confusa Merril	
	Spartium junceum L.	
13	*Medicago lupulina* L.	
	Trifolium hybridum L.	
	Desmodium polycarpum DC.	
	Anthyllis vulneraria DC. (L)	
	Indigofera viscosa Lam.	
	Crotalaria incana L.	
	Dalea alopecuroides Willd.	
14	*Wistaria chinensis* Nutt.	
	Robinia viscosum Vent.	
	Erythrina rubrinervia H.B.K.	
	Cajanus indicus Spreng.	

should be a reliable method for detecting self-sterility or self-compatibility, provided the plants are not wind-pollinated. Accordingly, racemes of flowers of *Cladrastis lutea*, a non-nodulating plant, were

TABLE 1.—*Continued.*

	Species of legume	Nature of pollination
15	*Desmanthus leptalobus* T.G.	Progressing from self-pollination toward cross pollination ↓
	Crotalaria polysperma Kotschy	
	Lotus corniculatus L.	
	Astragalus membranaceus Bunge	
	Glycyrrhiza lepidota Nutt.	
	Vigna affinis	
16	*Trifolium pratense* L.	
17	*Cassia chamaecrista* L.	
	Trigonella foenum-graecum L.	
	Petalostemon oligophylla	
	Vigna vexillata Rydb.	
18	*Crotalaria intermedia* Kotschy.	
	Crotalaria lanceolata E. Meg.	
	Astragalus cicer Linn.	
	Oxytropus lambertii Pursh	
	Erythrina crista galli L.	
	Pueraria hirsuta Schneid	
	Dolichos lignosus DC.	
19	*Vigna retusa* Walp.	
	Crotalaria alata	
	Ononis vaginalus Vahl.	
20	*Acacia decurrens* Willd.	
	Crotalaria hildebrantii Vetka	
	Ononis vaginalis Vahl.	
	Crotalaria juncea L.	
	Crotalaria sagittalis L.	
	Amorpha microphylla Pursch.	
	Colutea arborescens L.	
	Indigofera trita L.	
21	*Piptanthus nepalensis* D.	
	Crotalaria mundyi Baker	
	Onobrychis sativa Lam.	
22	*Galega hartlandii*	
	Crotalaria maxillaria	
23	*Desmodium canadensis* (L) DC.	
24	*Crotalaria falcata* Vahl.	
25	*Thermopsis caroliniana* M.A. Curt.	↑
	Amorpha elata Bouche	
	Astragalus rubyi	
	Kennedya monophylla Vent.	Progressing from obligatory cross-pollination toward self-pollination
26	*Medicago sativa* L.	
27	*Phaseolus vulgaris* L.	
28	*Amorpha fruticosa* L.	

TABLE 1.—*Concluded.*

	Species of legume	Nature of pollination
29	*Amorpha canencens* (Nutt) Pursh. *Crotalaria grantiana* Harvey *Centrosema virginianum* (L) Benth *Phaseolus coccineus* L.	↑
30	*Chorizema illicifolia* Labill *Robinia pseudo-acacia* L. *Sesbania macrocarpa* Muhl	Progressing from obligatory cross-pollination toward self-pollination

*Figures at the left of the brackets indicate the number of strains of *Rhizobium* out of 32 which have been observed to symbiose with the species of legumes to the right of the bracket.

thus protected. After sufficient time it was observed that practically every flower produced a pod. Plants of *Cassia tora*, also a non-nodulating plant, were grown from seed in the greenhouse where the flowers could not be worked by insects. Abundant seed formation was observed. Such data might indicate that all the species in the list of non-nodulating plants in Table 1 are self-pollinators.

Following those species that do not bear nodules come *Cicer arietenum*, *Ulex europaens*, *Dorycnium herbaceum*, and *Ornithopus sativus*, species that have been observed to symbiose with only one of the strains employed. The strain that symbiosed with *Cicer* was obtained from the Soviet Republic and was isolated from *Cicer* by S. G. Rasunowskaje of the University of Leningrad.[5] The strain that symbiosed with *Ulex* was isolated from *Stizolobium deeringianum* and was obtained from the U. S. Dept. of Agriculture. The strain that symbiosed with *Ornithopus* was isolated from *Lens esculenta* and the one that symbiosed with *Dorycnium* was isolated from *Caragana frutescens*.[6] The seven species in bracket 1 are probably all self-pollinating or nearly so. Howard, *et al.* (5) state that the anthers of *Cicer* dehisce and pollination occurs in the bud stage, insuring self-fertilization. Data from the literature on the degree of cross-pollination or self-fertilization for the other species and for a majority of the other plants listed in the table were not available. Cheesecloth bags, therefore, were placed around flowers of many species of legumes. By such a procedure it was observed that *Vicia pratensis* produced about as many seed pods in the bags as outside the bags, and it is a common observation of florists that unless the flowers of *Lathyrus odorata* are removed, seed pods will appear without the flowers having been visited by insects. Seed pods were readily produced in cheesecloth bags by *Caragana pekensis*, *Amphicarpa monoica*, *A. pitcherii*, *Trifolium agrarium*, *T. fragiferum*, *Medicago lupulina*, *Melilotus alba*, *Colutea arborescens*, and *Glycine max*. If the work of Garber and Odland (4) is consulted, it is evident that natural crossing with soybeans (Glycine) may vary more than 100% from one year to another, although the number of such natural crosses is rather small. Wood-

[5]Personal communication, 1935.

[6]A complete record of strains that symbiosed with each species can be found in Cornell Univ. Agr. Exp. Sta. Mem. 221. 1939.

worth (15) found only 0.16% natural crossing in this species. Racemes of flowers of *Baptisia australis* were also covered. In one case three pods developed on one raceme. Each pod had only a few seed instead of many as was the case with other pods not covered. The data in Table 1 show that *B. australis* symbiosed with only nine of the strains. Kirk (6) states that *Melilotus alba* sets seed when protected from visitation by insects, while *M. officinalis* did not do so under such conditions without artificial manipulation. In the table it can be seen that these last three species will symbiose with about 10 times as many strains of rhizobia as *Cicer* but with about only one-third of the strains employed.

Natural crossing in *Vigna sinensis* was found by Piper (9) to occur rarely in most localities but in some instances natural crossing occurred more frequently. If Table 1 is consulted, it can be seen that *Vigna* symbiosed with 11 of the strains. Fergus (2) reached the conclusion from artifically fertilizing heads of red clover that some lines were highly self-fertile and Williams (14) agrees with Fergus that the degree of self-sterility varies with different plants. It would seem, therefore, that red clover cross-pollinates more readily than *Vigna* does, and it is evident from Table 1 that *Trifolium pratense* will symbiose with a larger number of strains of *Rhizobium* than *Vigna*. Crosses may even occur between various species, for Piper, *et. al.* (10) found that pollen of *Medicago falcata* was as efficient in fertilizing *M. sativa* as pollen from other *sativa* plants. This fact was checked by Waldron (13) who planted the two species in equal numbers and grew plants the following year from the seed. The number of hybrids from *Medicago falcata* reached as high as 42.7%. The data presented in this paper show that *Medicago sativa*, a plant that can and may be highly cross-pollinated, will symbiose with 26 of the strains. Such comparisons are cited to emphasize the relationships that might exist between pollination and symbiosis.

Flowers of certain other species were covered to test the necessity of cross-pollination for seed production. About 800 flowers of *Robinia pseudo-acacia* were thus covered. Only three pods developed. One contained two seeds, the other two one seed each. Also, numerous flowers of *Chorizema illicifolia* developed in a greenhouse during a period of three seasons where they could not be visited by insects. Not a seed was ever observed unless the flowers were artificially manipulated. Similar results were obtained with flowers of *Erythrina crista galli*, except the flowers were never worked. Bags were placed over a large number of the flower racemes of *Amorpha fruticosa*. Although no counts were made, it was evident that the setting of seed was favored by the degree of visitation of insects. From the table it can be seen that plants as thoroughly dependent on cross-pollination as *Robinia*, *Chorizema*, *Amorpha*, and certain other legumes, will symbiose with about 30 times as many strains of the rhizobia as will *Cicer*, a self-pollinating plant.

The suggestion can be made after observing the data in Table 1 that as self-pollination becomes less frequent, the number of species of plants symbiosing with a larger number of strains increases. This tendency exists about one-half way through the list of 184 species.

As the end of the list is approached where cross-pollination is more and more obligatory, the number of species symbiosing with a constantly increasing number of strains drastically decreases.

In adaptation studies of strains of *Rhizobium* to other species of plants, the adaptation can be effected more easily if the strain is offered the opportunity to symbiose with a plant that carries about the same degree of cross-pollination as that from which the strain was isolated. If a strain is isolated from a species that is largely self-pollinating, such as *Vigna sinensis* or *Albizzia julibrissin*, it may be adapted to a large number of species of legumes, but if it is isolated from a species that is highly cross-pollinating, such as *Amorpha fruticosa*, *Phaseolus coccineus*, or *Chorizema illicifolia*, it may not be easily adapted to the self-pollinating plants. Much will depend, however, on the particular strain that is being employed in the test. Such a condition indicates that a strain isolated from a group of homozygous plants may also symbiose with a group of plants that is heterozygous. The reverse, however, may not be true because the strain of Rhizobium may be radically different. Such non-reciprocal relations have been described by Sears and Clark (1930).

Studies concerning the relationship between the morphology of the strains of the rhizobia and the nature of pollination should be mentioned. If in the whole group of rhizobia certain strains are considered as being predominantly monotrichic and others as predominantly multitrichic with all gradations of flagellation between, then a relationship between self- and cross-pollinating plants and the strain of *Rhizobium* with which they will symbiose becomes evident. Those strains that are predominantly monotrichic will, almost to the exclusion of all other strains, symbiose with plants that are self-pollinating or largely so, while those strains that are predominantly multitrichic will more often symbiose with species that are more freely cross-pollinating. In many instances, however, the predominantly monotrichic strains may be observed symbiosing with cross-pollinating plants. Thus, the predominantly monotrichic strain commonly encountered symbiosing with *Vigna sinensis*, a plant highly self-pollinating, will symbiose with *Amorpha fruticosa*, a plant highly cross-pollinating.

Since the degree of cross-pollination may be an index to the number of strains that will symbiose with a species, it may explain why various species of a genus appear scattered throughout the list in the Table 1. As an illustration, *Crotalaria verrucosa* appears in bracket 3, while *C. grantiana* appears in bracket 29. Seventeen other species appear between these extremes. It would be suspected, therefore, that *C. verrucosa* is highly self-pollinating, while *C. grantiana* is highly cross-pollinating, although data substantiating the suggestion are not available. Similar conditions exist with species of *Trifolium* and also with other species.

If the degree of selfing or crossing will influence the ratio of the species of a genus that will symbiose with certain strains of rhizobia, it might be possible to detect similar differences in various lots of seed from the same species. Thus, seeds of *Medicago sativa*, a plant that under certain conditions may be considerably self-fertilized and

under other conditions largely cross-pollinated, may exhibit such differences if seed containing certain heritable characters are properly tested. In this connection two lots of seed of Medicago were obtained. One was labeled alfalfa, while the other one was a self-tripping Grimm alfalfa. Seeds of these two lots were grown to ascertain their symbiobility with strains of rhizobia.

The results showed that the Grimm alfalfa symbiosed with the strains isolated from *Apios tuberosa*, *Caragana frutescens*, *Desmodium canadensis*, *Lespedeza striata*, *Medicago sativa*, and *Stizolobium deeringianum*. The other alfalfa did not symbiose with any one of the strains employed. It is suggested that other tests of this nature should be made before conclusions are drawn.

DISCUSSION

For the past 50 years botanists and agricultural bacteriologists have studied the legumes and their associated organisms. During this time about 20 plant-bacteria groups have been proposed. These groups are supposed to represent a rather specific relation between the plant and the particular strain of the bacteria. Unfortunately there are so many exceptions to the proposed groupings that one cannot use them with certainty. If a logical explanation could be offered for the exceptions it might lead to a better understanding of the whole situation. The suggestion is made in this report that a relationship exists between the degree of cross-pollination and the number of strains of *Rhizobium* with which a plant will symbiose. It appears that plants which are self-pollinating naturally contain or have developed comparatively pure lines which carry none or only a few characters that make symbiosis possible, or carry them in a recessive condition, while those plants that are cross-pollinating have developed or maintained to a surprising degree those characters in a dominant state which make it possible for the plants to symbiose with a large number of strains of the rhizobia. It seems that many unexplained facts can be accounted for if the symbiotic relation is a genetic one.

Just what percentage of crossing is obligatory to maintain the necessary degree of heterogeneity for symbiosis is not known. The data presented in this paper, therefore, are only relative and the position of certain plants listed in Table 1 may be shifted when further information is obtained. The fact that many data on the number of strains with which the plant will symbiose were obtained under conditions that might not have been altogether suitable for the plant or bacteria may also make necessary a relocation of certain plants. Also, if pollination produces different degrees of heterogeneity, it should be suspected that the particular sample of seed employed in a piece of work could hardly be duplicated at another time. This, however, would not obtain to the same degree with seeds from plants that are known to be homozygous or nearly so. The degree of selfing or crossing that occurs in any particular species in any one year may modify drastically the seeds of that species. This may offer an explanation of the frequently discussed practical question of having a culture for inoculating the crop composed of several strains. One strain might

symbiose adequately with one fraction of the seed and another strain with still another fraction. If the degree of cross-pollination is a factor influencing symbiosis, it should be suspected that a plant at one time would not symbiose with certain strains, while the seedlings from that plant might do so because of the heritable characters combined in the crossing. This means that a strain of *Rhizobium* could appear inefficient at one time and efficient at another. Thus, the plant probably becomes the dominant member in symbiosis because it is the one which can and might change its characters most readily through pollination. Probably one reason why more plants have not become non-nodulating is that a plant's own pollen may be non-compatible, or that only those plants survive which can nodulate. This makes it necessary that many species which survive remain heterozygous and thus maintain those characters that permit promiscuous symbiosis.

Since plant resistance to certain diseases is a genetic factor and may be dominant or recessive, depending upon certain relations, it would be interesting to know whether resistance to the legume bacteria is also a genetic factor and whether segregation for non-nodulation or nodulation would occur on a simple Mendelian 3:1 ratio. It is known, however, that cross-pollination often produces in the offspring increased growth or heterosis and this may account in part for the variation in nodulation.

SUMMARY AND CONCLUSION

Evidence has been presented to show that a relationship may exist between pollination and nodulation of species of legumes. Plants that are completely self-pollinating may not bear nodules, or if they do, the number of strains of rhizobia with which they will symbiose will be small. If cross-pollination is obligatory the number of strains with which the plant will symbiose will be comparatively large. The strains of rhizobia symbiosing with self-pollinating plants appear predominantly monotrichic, while those that symbiose with cross-pollinating plants appear predominantly multitrichic, although both morphological types may be found symbiosing with cross-pollinating plants. Such a relationship apparently does not correlate in any way with the order, tribe, genus, or species of the plants, except as it may be influenced by pollination. If this suggested relationship is valid it will place symbiosis on a heritable basis and in the same category as are certain heritable plant diseases.

LITERATURE CITED

1. Baldwin, I. L., Fred, E. B., and Hastings, E. G. Grouping of legumes according to biological reactions of their seed proteins. Bot. Gaz., 83:217–243. 1927.
2. Fergus, E. N. Self-fertility in red clover. Ky. Agr. Exp. Sta. Circ. 29. 1922.
3. Fred, E. B., and Davenport, A. Influence of reaction on nitrogen-assimilating bacteria. Jour. Agr. Res., 14:317–336. 1918.
4. Garber, R. J. and Odland, T. E. Influence of adjacent rows of soybeans on one another. Jour. Amer. Soc. Agron., 18:605–607. 1926.
5. Howard, A., Howard, F. L. C., and Khan, A. R. Some observations of Indian Grain (*Cicer arietinum* L.) Mem. Dept. Agr. India, Bot. Ser., 7:213–235. 1915.

6. KIRK, L. E. Breeding sweet clover and lucerne. Imp. Bureau Plant Gen. Herb. Plants. Bul. 7. 1927.
7. MAZÉ, M. Les microbes des nodosites des Légumineuses. Ann. Inst. Pasteur, 13:145–155. 1899.
8. MCDOUGALL, W. B. Thick-walled root hairs of Gleditsia and related genera. Amer. Jour. Bot., 8:171–175. 1926.
9. PIPER, C. V. Agricultural varieties of the cowpea and immediately related species. U. S. D. A. Bur. Plant Ind. Bul. 229. 1912.
10. ————, EVANS, M. W., MCKEE, B., and MORSE, W. J. Alfalfa seed production, pollination studies. U. S. D. A. Bul. 75. 1914.
11. SEARS, O. H., and CLARK, F. M. Non-reciprocal cross-inoculation of legume nodule bacteria. Soil Science, 30:237–242. 1930.
12. SÜCHTING, H. Kritische studien über die Knollchenbakterien. Cent. Bakt. (etc.) 2 Abt., 11:377–388; 417–441; 496–520. 1904.
13. WALDRON, L. R. Cross-fertilization in alfalfa. Jour. Amer. Soc. Agron., 11:259–266. 1919.
14. WILLIAMS, R. D. Studies concerning the pollination, fertilization and breeding of red clover. Univ. College Wales. Welsh Plant Breed. Sta. Ser. H No. 4. 1925.
15. WOODWORTH, C. M. The extent of natural cross-pollination in soybeans. Jour. Amer. Soc. Agron., 14:481–495. 1922.

NOTE

A MIXER AND SAMPLER FOR GREENHOUSE SOILS

IN greenhouse pot culture work it is frequently desirable to mix a small quantity of fertilizer with 4 to 10 kilograms of soil. Again it often becomes necessary to analyze the soil in greenhouse pots. It is difficult in such an analysis to obtain a small sample which is a true aliquot of an entire pot of soil. The mixing of 8 to 10 kilograms of soil on an oilcloth with sufficient thoroughness to make possible the removal of a small representative sample is extremely difficult. Accordingly, a mechanical mixer and sampler was constructed and has been used in the soils greenhouse of the Michigan Agricultural Experiment Station for two years. A description of the apparatus follows.

As shown by Fig. 1, the mixer consists of a 15-inch cubical sheet metal box with rounded corners and with a ½-inch steel shaft passing through diagonally opposite corners. A crank on one end of the shaft is used to turn the mixer. The cover, consisting of about three-fourths of one side of the mixer, is on hinges and is fastened by means of screw clamps which slip apart as soon as they are loosened. This arrangement makes it easily opened. A rubber gasket keeps the soil from sifting out during mixing.

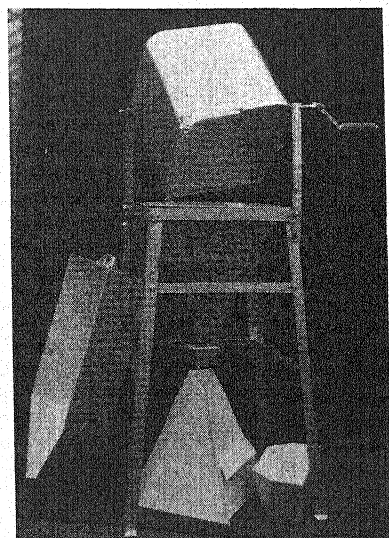

FIG. 1.—A mixer and sampler designed for use in mixing fertilizers with greenhouse soils and in sampling greenhouse pot culture soils for chemical analyses.

As the mixer is turned, the soil rolls from corner to corner six times during each revolution. To hasten the mixing two 3-inch triangular baffle plates were welded into the edges opposite the cover and half way between the corners. As the mixer is turned these plates carry a portion of the soil up and allow it to fall on top of the remainder.

The sampler consists essentially of two parts, a square funnel, 16 inches at the top and 3 inches at the bottom, and a pyramid 17 inches high with a 12-inch square base. The funnel is fitted with a slide to hold the soil. The edges of the pyramid are turned out a distance of 1½ inches and one side is fitted with a piece of metal so arranged as to direct soil into a small tray made for that purpose.

In operation the pyramid is placed under the funnel. The height of the 1½-inch angle iron frame is such (38 inches) that the funnel comes down over the top of the pyramid. When the slide is quickly

TABLE 1.—*The results of nitrogen tests made to show the efficiency of the soil mixer and sampler shown in Fig. 1.*

Sample No.*	Percentage of total nitrogen in replicated pots†										
	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Pot 6	Pot 7	Pot 8	Pot 9	Pot 10	Mean
1	0.149	0.150	0.152	0.149	0.151	0.151	0.150	0.151	0.156	0.150	0.1509
2	0.151	0.147	0.152	0.152	0.148	0.153	0.149	0.152	0.155	0.153	0.1512
3	0.149	0.152	0.152	0.151	0.152	0.153	0.149	0.151	0.156	0.151	0.1516
4	0.151	0.153	0.150	0.152	0.152	0.149	0.149	0.150	0.154	0.151	0.1511
Mean	0.1500	0.1505	0.1515	0.1510	0.1508	0.1515	0.1493	0.1510	0.1553	0.1513	0.1512

*One sample was taken for analysis from each quarter of each pot of soil.
†Each pot of 10 kg. of soil was treated with 50 grams of $(NH_4)_2SO_4$.

removed, the soil from the funnel is divided into four almost equal portions. One portion is caught in the small tray and is returned to the funnel for another quartering. Three quarterings will thus reduce a 10,000-gram pot of soil to approximately 150 grams. By returning the soil sample to the funnel in a paper it is possible to eliminate an error caused by the larger particles becoming separated from the finer during the process of pouring it into the funnel.

The large tray, 18 x 30 inches, is placed under the pyramid and smaller tray during operation.

To test the thoroughness with which this apparatus will mix a pot of soil, 10 pots were filled with 10 kilograms each of Plainfield sand. To each pot was added 50 grams of $(NH_4)_2SO_4$. The contents of each pot was then mixed by turning it 25 times in the mixer.

The cultures were then wetted and kept at optimum moisture for 18 days, after which the soil in each culture was dried and again mixed by turning 50 times in the mixer. By means of the divider each culture was then quartered and a sample taken from each quarter for analysis. Total nitrogen by the Kjehdahl method was determined on each sample. Based on the mean percentage of nitrogen, the recovery of applied nitrogen was 96.84%. Nitrate nitrogen was not determined.

According to the data presented in Table 1, the variations in the percentage of nitrogen between samples from the same pot were very slight. Considering the means for the 10 pots, this percentage ranged from 0.1509 to 0.1516. To determine the significance of the mean differences the data were analyzed by analysis of variance. As shown by the results of this analysis (Table 2), a between sample variance of 0.00000087 compared to an error variance of .00000235 (F equals 2.701) shows there was not a significant difference between the means of any two samples. This proves that each pot of soil was thoroughly mixed when the samples were taken.

TABLE 2.—*Analysis of variance for nitrogen tests made to show efficiency of soil mixer and sampler shown in Fig. 1.*

Source of variation	Degrees of freedom	Sum of squares	Variance	F	Estimate of S. D.
Total	39	.0001564			
Between samples	3	.0000026	.00000087	2.701	
Between pots	9	.0000904	.00001004	4.272	
Error	27	.0000634	.00000235		.001533

The results do show, however, that a difference existed between the nitrogen contents of various pots. A variance of 0.00001004 between pots resulted in an F value of 4.272, significant to the 1% point. A test for significance between the means of pots shows that pot 9 contained a significantly higher percentage of nitrogen than did any of the other pots but that no significant difference existed between any of the other means. In other words, when pot 9 was eliminated the analysis of variance for the data from those remaining shows that there was not a significant difference between any of the means. The variance between pot 9 and the other pots may have been caused by several factors. Perhaps an error was made in weighing the ammonium

sulfate or there may have been a difference in the rate of nitrification in that pot as compared to the others. This could have resulted from either a lower or higher moisture content. If the rate of nitrification was lower, the quantity of nitrogen remaining in a form which could be determined by the Kjeldahl method would have been correspondingly higher.

As a result of these data it seems safe to conclude that the apparatus described is capable of thoroughly mixing a 10-kilogram sample of soil.—R.L. COOK, *Soils Section, Michigan State College, East Lansing, Michigan.*

BOOK REVIEW

STATISTICAL TABLES FOR BIOLOGICAL, AGRICULTURAL, AND MEDICAL RESEARCH

By R. A. Fisher and F. Yates. Edinburgh: Oliver and Boyd. VIII+90 pages. 1938. 12/6.

WHILE this attractive volume includes those tables familiar to all readers of Professor Fisher's "Statistical Methods for Research Workers," it contains a notable amount of useful material besides. Of especial interest to the agronomist is the attention devoted to the mechanism of designing experiments in agriculture. One is somewhat startled at first sight of the four large pages of Latin squares, including the complete sets of orthogonal squares 9×9 and smaller. These, supplemented by the six pages of random numbers, are useful in designing various types of complex experiments. Following them are other tables with special solutions of balanced incomplete blocks and a convenient index for picking out the design that meets the requirements of the experimenter. While a liberal amount of explanation is given in the introduction, the reader is not advised to attempt to design and analyze a complex experiment before a careful study of the references listed.

With the rapid development of the applications of polynomial fitting by Fisher, Hopkins, Tippett, Wishart, Kalamkar, Cochran, and others, the investigator in agronomy using this method will welcome the labor-saving devices made available in these tables. Since orthogonal polynomials promise great advances in the examination of weather-crop relations and growth curves, any lightening of the labor of computation is a welcome contribution.

In some plat experiments the investigator is concerned with counts of infested or diseased plants, often expressing the results as percentages. If the distributions are not normal the F-test of significance in analysis of variance may be invalid. Appropriate transformations are discussed in these tables. Emphasis is laid on the probit transformation of Bliss, complete tables being quoted together with a worked-out example. Angle and other transformations are specified.

The tables peculiar to Professor Fisher's developments of statistical methods are supplemented by the customary logarithms, squares, square roots, reciprocals, sines, tangents, etc. Those who deal with ranked data will be interested in a table for transforming these into normally distributed scores. Many people who object to the use of an auxiliary table of natural logarithms for making the z-test will be pleased to find F tabulated under the caption, "Variance Ratio."

The agronomist will find this book of tables a useful addition to his kit of statistical tools. (G. W. S.)

All essays must be prepared by undergraduate students. Students graduating during the course of the 1938–39 school year or those graduating during the summer school of 1939 are eligible, providing their papers are submitted before graduation. A certification of eligibility to qualify as an undergraduate, signed by the Dean of the College, must accompany each paper.

Papers should be typed, double spaced and not over 3500 words in length. *Abstracts of not more than 500 words must accompany each paper.* Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper.

The title for the essay shall be "The Work of Early American Agronomists".

"Early Agronomists" is taken to mean any agronomist no longer living. Not less than one nor more than four men are to be considered in the essay.

All papers are to be submitted in duplicate and if it is desired that the essay be returned, postage should be enclosed.

The committee suggests, that where several papers are entered from a given institution, the local representatives of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expense.

Essays must be in the hands of the Chairman of the Committee on Student Sections, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than August 1, 1939.

NEWS ITEMS

DR. JOHN H. PARKER, Professor in Charge of Crop Improvement, Kansas State College, has resigned after 21 years of service to become Director of the Kansas Wheat Improvement Association. Dr. Parker's address will continue to be Manhattan, Kansas.

LOUIS P. REITZ, U. S. Dept. of Agriculture, has been appointed as Associate Professor in Charge of Crop Improvement, Kansas State College, to succeed Dr. John H. Parker, resigned. Mr. Reitz' appointment took effect February 1, 1939.

JOURNAL

OF THE

American Society of Agronomy

VOL. 31 | MARCH, 1939 | NO. 3

SCARIFICATION STUDIES ON SOUTHERN GRASS SEEDS[1]

GLENN W. BURTON[2]

PASTURE men report that considerable difficulty is experienced in establishing some of the southern grasses with seed. While environmental factors probably play the dominant rôle in the successful establishment of pastures from seed, the poor quality of the seed planted may often explain the failures which result. Numerous studies made with the aid of a seed blower[3] indicate that from 50 to 75% of the florets of many southern grasses often fail to form caryopses. The complete separation of empty florets from those containing caryopses with ordinary seed cleaning machinery is difficult, and, hence, seed may appear upon the market which germinates poorly because of the large percentage of empty florets present. Ergot, *Claviceps paspali*, on Dallis grass, *Paspalum dilatatum*, and Bahia grass, *Paspalum notatum* and *Cerebella paspali* on carpet grass, *Axonopus affinis*, attack the caryopses and may be so severe as greatly to reduce the number of seedlings expected from a pound of seed.

Germination studies made in 1936 upon florets containing sound caryopses indicate that delayed germination was often experienced. Ray and Stewart[4] make reference to this condition in *Paspalum dilatatum*, *P. floridanum*, and *P. pubiflorum* and indicate that removal of the lemma and palea or scarification with 37% HCl for 3 to 10 minutes in the case of *P. dilatatum* will cause the seed to germinate more readily. Southern weeds and annual grasses grow so rapidly in freshly prepared soil that pasture grass seedlings appearing 3 to 6 weeks after planting usually experience very severe, and often fatal, competition. Any treatment which will hasten the germination and

[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Agricultural Experiment Station, and the Georgia Coastal Plain Experiment Station at Tifton, Georgia. Received for publication December 8, 1938.

[2]Agent, U. S. Department of Agriculture, Tifton, Georgia.

[3]BURTON, GLENN W. A useful seed blower for the grass breeder. Jour. Amer. Soc. Agron., 30:446–448. 1938.

[4]RAY, C. B., and STEWART, RALPH T. Germination of seeds from certain species of Paspalum. Jour. Amer. Soc. Agron., 29:548–554. 1937.

early growth of these grasses should give them a better chance to meet this unfavorable competition successfully.

Bahia grass, *Paspalum notatum*, has been one of the most promising pasture plants grown in south Georgia and Florida. The scarcity of viable seed of this species has been the principal factor limiting its use. Seed yields made on some 3,500 seedlings indicate that desirable strains producing 300 to 600 pounds of seed per acre can be found. It is apparent from the following results, however, that the chances of selecting a strain capable of producing seed which will germinate readily are not great.

To determine the ability of different plants to produce seed which will germinate rapidly, 100 seeds (florets containing caryopses) from each of 175 Bahia grass plants were sown in flats of steam-sterilized soil in the greenhouse on September 4, 1937. These were kept moist at temperatures ranging from 75° to 100° F throughout the test. On October 1, from one to two seeds had germinated in 28 of the rows and none of the other 147 samples showed any sign of growth. By October 15 only 76 samples had begun to germinate, and on December 8, more than 3 months after planting, 35 rows had still failed to germinate and the other 140 samples averaged 3.2 seedlings per 100 seed planted. One lot of seed, after 3 months, germinated 22%; the next best sample, 11%.

EXPERIMENTAL

All germination studies described here were made by planting 100 seeds (florets containing caryopses unless otherwise specified) in rows in flats of steam-sterilized soil in the greenhouse. The steam-sterilized soil was rendered free of toxic substances by leaching prior to its use. The soil was kept moist throughout each test. The temperature varied with the season, being somewhat warmer during the summer than in mid-winter. The source of seed used in these studies may be found in the tables.

Most of the seed treatments, listed in the tables and chosen with the thought of increasing the permeability of the seed to water, need no description. The success experienced with the use of dry heat to scarify alfalfa seed made a heat treatment seem desirable. All acid and alkali treatments were made by stirring a small quantity of seed in a beaker of the scarifying medium for the period designated. The seeds were then washed in running water for 5 to 10 minutes and finally spread out to dry.

RESULTS

From Table 1 it is apparent that subjecting Bahia grass seed to 70° C for 4 hours, or soaking them in water with and without reduced pressure, does not increase significantly the rate of germination. Removing the palea and both glumes with sandpaper scarification, however, did hasten germination materially. The variation in response to sandpaper scarification noted in the 1936 and 1937 seed is due to the fact that the 1936 seed, being drier than the 1937 sample, had to be rubbed harder to remove both glumes and more of the caryopses were cracked and apparently killed. Treatment of the 1936 seed with concentrated H_2SO_4 for 5 minutes caused the seed to germinate 32% in 1 week, and 56% 2 weeks after planting as com-

pared with 0 and 9% for untreated seed. Increased germination was also obtained following H_2SO_4 scarification of the 1937 seed. Treatment of Bahia seed for 5 minutes with concentrated HCl had very little effect on the germination rate.

TABLE 1.—*The influence of various seed treatments upon the germination of Bahia grass seed planted in triplicate in steam-sterilized soil in the greenhouse, August 7, 1937.**

Seed treatment	Seed harvested Aug. 31, '36, % germination after			Seed harvested Aug. 3, '37, % germination after		
	6 days	13 days	20 days	6 days	13 days	20 days
No treatment	0	9	24	0	1	1
70° C for 4 hours	0	14	23	0	0	1
Soaked in water 24 hours	2	14	24	0	2	2
Soaked in water 24 hours and suction	0	14	27	0	0	1
Palea removed	12	13	17	6	19	26
Sandpaper scarification†	6	11	11	40	49	52
Conc. technical H_2SO_4 for 5 minutes	32	56	57	2	14	16
Conc. HCl for 5 minutes	1	7	11	0	0	5

*The 1936 and 1937 seed tested here was harvested from the same plat of Bahia grass growing at Tifton, Georgia. Prior to the test, the seed was stored in a semi-basement room where humidity was slightly above normal.

†Seeds were rubbed between sandpaper blocks until the caryopses were freed from the glumes.

The immediate germination of the 1937 seed, following removal of the glumes, indicates that Bahia grass seed unlike many other grasses requires little if any rest period. Other experiments not reported here substantitate this conclusion.

The germination of 9 and 24% obtained on the untreated 1936 seed 2 and 3 weeks after planting is the best germination of untreated Bahia seed recorded in the many tests run at Tifton. This test suggests that 1-year-old Bahia grass seed will germinate better than freshly harvested seed. In Table 2, however, this same untreated 1936 seed, 3 weeks after planting, germinated only 0.3%. This difference is believed to be due to the variation in greenhouse temperatures. In August when the first test was made, mean temperatures fluctu-

TABLE 2.—*The effect of the time factor in the acid scarification of Bahia grass seed planted in triplicate in steam-sterilized soil in the greenhouse October 1, 1937.**

Length of time seed were stirred in conc. technical H_2SO_4	Seed harvested Aug. 31, '36, % germination after			Seed harvested Aug. 3, '37, % germination after		
	8 days	14 days	21 days	8 days	14 days	21 days
No treatment	0	0	0.3	0	0	0.3
2½ minutes	5	13	17	10	24	31
5 minutes	11	22	26	13	28	34
10 minutes	42	60	64	52	56	57
15 minutes	48	66	70	39	45	46

*The seeds in this test were taken from the same seed lots used in the test included in Table 1.

ated between 85° and 90° F, while in October, when the second test was carried out, mean temperatures ranged around 70° F.

The failure to devise a mechanical scarifying apparatus which would remove most of the glumes and not crack many of the flat caryopses made acid scarification seem the most practical method of increasing the germination rate of Bahia grass seed. To determine the optimum period of treatment, the experiment presented in Table 2 was set up. The results given in Table 2 show that a 10-minute scarification in concentrated technical H_2SO_4 for the 1937 seed and a 15-minute treatment for the 1936 seed induced a 52 and 48% germination 8 days after planting. Untreated seed germinated 0.3% 3 weeks after they were planted. The reduced germination obtained from treating the 1937 seed for 15 minutes indicates that some of the seeds were injured by this treatment. All of the 1936 seed was completely ripe when harvested, while some of the 1937 seed was slightly green. It is possible that the glumes on these green seeds were not quite so waxy as those on the 1936 seed and hence could not tolerate as much scarifying action.

The effect of several scarification treatments upon the seed of five southern grasses is presented in Tables 3 and 4. From Table 3 it is apparent that treating unhulled Bermuda grass, *Cynodon dactylon*, seed with concentrated HCl for 5 minutes will hasten germination. It is possible that a longer treatment in HCl would increase the germination rate, but 5 minutes in concentrated technical H_2SO_4 apparently killed most of the seeds.

TABLE 3.—*The influence of various seed treatments upon the germination of Vasey grass, Bermuda grass, and carpet grass seed planted in triplicate in steam-sterilized soil in the greenhouse October 19, 1937.*

Treatment	Percentage germination after		
	22 days	32 days	50 days
Commercial Unhulled Bermuda Grass Seed, 1936 Crop			
No treatment	5	11	13
70° C for 17 hours	3	8	11
Conc. HCl, 5 minutes	14	17	20
Conc. technical H_2SO_4, 5 minutes	0.6	0.6	1
Sandpaper scarification*	6	6	7
Vasey Grass Seed Harvested at Tifton, July 5, 1937			
No treatment	57	64	64
70° C for 17 hours	17	22	24
Conc. HCl, 5 minutes	8	11	12
Conc. H_2SO_4, 5 minutes	7	8	8
Conc. technical H_2SO_4, 10 minutes	0.6	0.6	0.6
Sandpaper scarification*	0.3	0.6	0.6
Commercial Carpet Grass Seed, 1936 Crop			
No treatment	66	74	74
Conc. HCl, 5 minutes	19	22	23
Conc. technical H_2SO_4, 5 minutes	29	37	37

*Seeds were rubbed between sandpaper blocks until the caryopses were freed from the glumes.

TABLE 4.—*The influence of various seed treatments upon the germination of Dallis grass and centipede grass seed planted in triplicate in steam-sterilized soil in the greenhouse, December 30, 1937.*

Treatment	Period of treatment in minutes	Percentage germination after		
		11 days	20 days	40 days
Commercial Dallis Grass Seed Produced in 1937 at Hamburg, La.*				
No treatment	—	4	9	17
Conc. technical H_2SO_4	5	21	24	29
Conc. technical H_2SO_4	10	12	13	15
Conc. technical H_2SO_4	15	4	4	6
Conc. technical H_2SO_4	20	2	2	2
35% NaON	5	6	12	22
35% NaOH	10	4	12	30
Centipede Grass Seed Harvested at Tifton, 1937				
No treatment	—	0	3	26
50% HCl	5	0	10	36
50% HCl	10	0	7	37
35% NaOH	5	0	8	34
35% NaOH	10	0	6	25

*No effort was made to separate ergots or empty florets from this seed.

Since the glumes enclosing the caryopses of Vasey grass, *Paspalum urvillei*, and carpet grass, *Axonopus affinis*, are not heavy and do not clasp the caryopses tightly, increased germination from scarification would not be expected. Table 3 shows that these seeds germinate well without treatment and that those treatments most successful in increasing the germination rate of Bahia grass greatly reduce the viability of carpet grass and Vasey grass seed.

Ray and Stewart[5] working with Dallis grass seed, report that, "Treating the seeds with 37% hydrochloric acid for 3 minutes and no longer than 10 minutes slightly increased their germination". The results presented in Table 4 show that the scarification of Dallis grass seed in concentrated technical H_2SO_4 for a period of 5 minutes may be expected to increase the germination rate materially. That NaOH may also be used as a scarifying agent is suggested by the slightly increased germination percentages obtained from its use.

Centipede grass, *Eremochloa ophiuroides*, is one of the most desirable southern lawn grasses. As the cost of establishing a lawn of this grass by planting stolons (the common practice) is high, an attempt was made in 1937 to harvest a small quantity of seed to be used in the experimental seeding of a lawn. Five pounds of seed were harvested, cleaned, and threshed at a cost of about 40 cents per pound. The delayed germination of these seeds (the caryopses thresh out free from the glumes) and the waxy appearance of the caryopses suggested that mild scarification treatments might hasten the growth of this seed. Table 4 shows that 5- and 10-minute treatments with either 50% HCl or 35% NaOH increased noticeably the germination rate of centipede grass seed.

[5]*Loc. cit.*

On February 22, 1938, the 5 pounds of centipede grass seed, two-thirds of which had been scarified in 50% HCl for 5 minutes, were used to seed 10,000 square feet of lawn surface. A satisfactory stand was obtained from this seeding. The ability of these centipede grass seedlings to compete favorably with crab grass and the other annual weeds during the summer of 1938, the driest on record at Tifton, demonstrates the practicability of establishing lawns of this grass from seed.

Since the crude sulfuric acid used in the manufacture of superphosphate is much cheaper than technical H_2SO_4, it seemed that its merits as a scarifying agent should be investigated. The results of an experiment set up for this purpose are presented in Table 5 and show that a 45- to 60-minute treatment in crude H_2SO_4 and a 10-minute treatment in technical acid were most satisfactory. The injury resulting from the treatment of this lot of seed for 15-, 20-, and 30-minute periods in technical H_2SO_4 demonstrates the care which must be taken when treating seed in this medium. Although more time is required to treat Bahia grass seed with crude sulfuric acid, it is undoubtedly a safer and much cheaper scarifying material than technical H_2SO_4. Diluting technical acid with water to approximately 75% H_2SO_4 might render it as safe as crude acid.

TABLE 5.—*The effect of technical and crude sulfuric acid scarification upon Bahia grass seed planted in duplicate in steam-sterilized soil in the greenhouse March 3, 1938.**

Treatment	Period of treatment in minutes	Percentage germination after		
		11 days	18 days	25 days
No treatment	—	0.5	14	25
Technical H_2SO_4	10	38	54	54
Crude H_2SO_4	10	1	38	60
Technical H_2SO_4	15	11	12	11
Crude H_2SO_4	15	1	49	68
Technical H_2SO_4	20	0.5	0.5	1
Crude H_2SO_4	20	4	56	70
Technical H_2SO_4	30	0	0	0
Crude H_2SO_4	30	4	48	60
Crude H_2SO_4	45	7	59	73
Crude H_2SO_4	60	8	64	70

*Technical H_2SO_4, specific gravity 1.84, over 94% H_2SO_4; crude H_2SO_4 used in manufacture of super phosphate fertilizer, specific gravity 1.69, about 78% H_2SO_4.

A viability test made recently on Bahia grass seed stored at room temperatures for 8 months after its treatment with H_2SO_4 indicates that acid scarification reduces the longevity of the seed and suggests that seed should not be scarified many weeks prior to planting.

In an attempt to make the acid scarification of large quantities of seed practical, the treating apparatus shown in Fig. 1 was devised. In treating the seed, the perforated drum is filled about half full of seed and is rotated slowly in the acid tank for the required period of time. The water tank surrounding the acid tank absorbs the heat generated by the action of the acid on large quantities of seed. In the

treatment of quantities of seed with technical H_2SO_4 without agitation and without a water bath surrounding the acid tank, the heat liberated was sufficient to decompose the acid and kill the seed. After the treatment the excess acid is allowed to drain back into the acid tank and the seeds are then washed by rotating the drum in the water tank. By running fresh water into the water tank with a hose, the acid left after washing the seed is removed and the temperature of the water is kept down. When thoroughly washed, the seeds are removed from the drum and spread in the sun to dry. The scarification

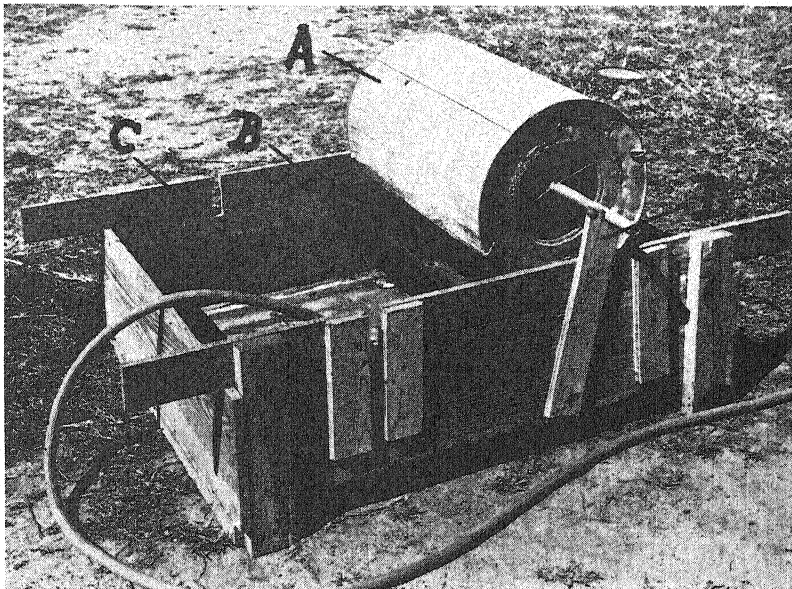

FIG. 1.—Acid scarifying machine. A, seed drum (an old calcium arsenate drum perforated with nail holes); B, acid tank (half of a 50-gallon steel barrel); C, water tank; D, standards for resting drum while excess acid is drained back into the acid tank.

periods shown to be most satisfactory in small tests are suitable for treating larger quantities of seed with this apparatus. Experience with the scarification of different seed lots within the same species proves that the optimum period of treatment for one sample may not be the same for another. The wisdom of making several small preliminary treatments before treating large quantities of seed is apparent.

The materials used in the construction of the scarifying machine shown in Fig. 1 cost about \$4.00. By using the acid left after treating the first drum of seed to treat a second lot, it is possible to treat 1 pound of Bahia grass seed with 2 pounds of acid. Crude H_2SO_4 can be delivered f.o.b. Tifton, Georgia, in tank car lots for \$10.50 per ton and can be purchased in barrel lots from a local fertilizer plant for 1

cent per pound. A small machine, similar to the one shown in Fig. 1, has been used in treating small lots of seed in the laboratory.

Field experiments set up in 1938 to test the value of acid scarification in the establishment of Bahia grass failed, due to the lack of moisture. During the 1938 growing season, the Tifton area received less than half of its normal rainfall. A shower caused the acid-scarified seed to germinate quite readily, but the subsequent drought killed most of the seedlings.

There is little doubt but that the scarification of the seed of Bahia grass and some other species will increase the chances of their successful establishment. Acid scarification of seed even with the best equipment is not a pleasant task. It is hoped that a satisfactory mechanical method of removing the glumes from Bahia grass and Dallis grass will be found. Until such a method is available it seems that acid scarification may be resorted to with profit.

SUMMARY

1. The large percentage of empty florets, delayed germination and ergot are some of the factors which reduce materially the chances of successfully establishing some of the southern grasses from seed.

2. Seed yields taken on 3,500 Bahia plants at Tifton indicate that strains capable of producing 300 to 600 pounds of seed per acre can be found.

3. Seed samples taken from 175 different Bahia grass plants were planted in steam-sterilized soil in the greenhouse and optimum growing conditions were maintained throughout the experiment. Three months after these samples were planted, 35 of them still showed no signs of life and an average viability of 3.2% was obtained in the remaining 140 seed lots.

4. All germination tests were made by planting 100 seeds in duplicate or triplicate in flats of steam-sterilized soil in the greenhouse. Seedling counts were usually made at weekly intervals thus giving the effect of the various treatments on the germination rate.

5. Seventy degrees C dry heat for 4 hours, soaking in water 24 hours with and without reduced pressure, and treatment with concentrated HCl for 5 minutes did not increase the germination of Bahia grass seed significantly.

6. Removing the palea, treating the seed in concentrated technical H_2SO_4 for 5 minutes, and removing both lemma and palea by rubbing the seeds between sandpaper blocks (the dry 1936 seed had to be rubbed so hard that many of the flat caryopses were cracked and killed) hastened germination materially.

7. Higher germination rate obtained with 1-year-old untreated Bahia grass seed as compared with fresh seed suggests that a change favoring germination occurs in storage.

8. Immediate germination of the 1937 seed following removal of the glumes indicates that Bahia grass seed, unlike many other grasses, requires little if any rest period.

9. Scarification of the 1937 seed in concentrated technical H_2SO_4 for 10 minutes and of the 1936 seed for 15 minutes induced a 52 and

48% germination 8 days after planting. Untreated seed germinated 0.3% 3 weeks after they were planted. The reduced germination obtained from treating the 1937 seed for 15 minutes indicates that some of the seeds were injured and that the optimum period of treatment for different lots of seed may not be the same.

10. Treating unhulled Bermuda grass seed with concentrated HCl for 5 minutes increased the germination rate. A 5-minute treatment in concentrated technical H_2SO_4 apparently killed most of the seeds.

11. Seed of Vasey grass and carpet grass germinated readily without treatment. All scarification treatments reduced the viability of these seeds.

12. Scarifying Dallis grass seed with concentrated technical H_2SO_4 for 5 minutes hastened germination materially. The value of 35% NaOH as a mild scarifying agent was demonstrated.

13. Five and 10-minute treatments with either 50% HCl or 35% NaOH increased the germination rate of centipede grass seed. The practicability of establishing centipede lawns from seed was demonstrated.

14. Scarification of Bahia grass seed with crude sulfuric acid (used in making superphosphate) for 45 to 60 minutes proved about as effective as a 10-minute scarification in concentrated technical H_2SO_4. Since crude sulfuric acid is much cheaper than technical acid, and since there is less danger of killing the seed from over-treatment, its use is recommended.

15. A viability test on Bahia grass seed stored at room temperature for 8 months after its treatment with H_2SO_4 indicates that acid scarification reduces the longevity of the seed.

16. Field tests made in 1938 demonstrated that acid-scarified Bahia grass seeds germinated quite readily. Prolonged drought subsequent to the emergence of the seedlings killed most of them, making the determination of the effect of seed treatment upon the establishment of the grass impossible.

17. A machine which will facilitate the acid scarification of rather large quantities of seed is described.

THE ADAPTABILITY OF RAPID CHEMICAL TESTS FOR USE IN DETERMINING THE NUTRIENT NEEDS OF SOUTH CAROLINA SOILS[1]

FRANK MOSER[2]

THE nutrient content of soils has been determined for a long time by the use of relatively strong extracting agents. However, no close correlation has been found between the nutrients so determined and the growth response of crops resulting from the addition of available plant nutrients. This lack of correlation has led to the use of weaker extracting agents in determining the availability of soil nutrients.

During the last decade much progress has been made in developing soil tests for determining the availability of plant nutrients culminating in the "rapid or quick test". Morgan (9),[3] Truog (16), Spurway (13), Bray (2, 3), Thornton, Conner and Frazer (14), Hester (7), and others have contributed much to the development of these methods and have created a wide interest in their application to fertilizer practice. According to a recent survey by Thomas (15), the rapid soil test methods are being used by some of the state experiment stations to estimate nutrient deficiencies in soils. The results of these tests are used as a supplementary aid for making fertilizer recommendations to farmers who request that their soil be tested. Most of the emphasis is placed on pH value or lime requirement, and phosphorus and potash availability. Some consideration may also be given such elements as nitrogen, calcium, magnesium, manganese, iron, and aluminum.

Considerable attention has already been given by research workers to the adaptability of these tests to intensive crop production in the Southeast. The work of Hester (7, 8) in Virginia on truck crops has been highly significant. In other sections a fair degree of correlation has been found between yield data and results of rapid tests.

Although these rapid tests have been perfected with respect to chemical procedures and technic, they differ considerably in their adaptability for use under various crop and soil conditions. These different methods have been developed to meet the needs of various local areas and are not necessarily adapted for use in all areas. This study was undertaken to determine which tests are more suitable for use in Piedmont and Coastal Plain areas of South Carolina, and also to determine the reliability of such tests for predicting responses from fertilizer applications.

EXPERIMENTAL PROCEDURE

Soil samples were secured from the plats used for cotton fertilizer experiments near Greer and Gaffney in the Piedmont section and from the Pee Dee and Truck Experiment Station areas in the Coastal Plain. The samples for analysis were

[1]Technical Contribution No. 59 from the Department of Agronomy, South Carolina Agricultural Experiment Station, Clemson, S. C. Received for publication August 31, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 199.

taken during April 1937 before the fertilizer was applied with a soil auger. From 15 to 20 borings to a depth of 7 inches were composited from each 1/20 acre plat for the laboratory analysis. A portion of each sample which was to be used for the rapid tests was passed through a 2-mm sieve, while another portion was passed through a 0.5-mm sieve for the Truog-Myer (17) method which was used as a basis in comparing the tests for determining available phosphorus. The exchangeable potassium was determined by leaching the soil with normal ammonium acetate solution, according to the method proposed by Schollenberger and Dreibelbis (12). The potassium was then determined in the leachate by the sodium cobalti-nitrite method of Volk and Truog (18). These authors found this method to give results in close agreement with crop responses to fertilizer.

The Universal, Purdue, Simplex, LaMotte, and Bray rapid testing methods were chosen for comparison. All the equipment for the various tests was either purchased from the manufacturers or was made up according to published specifications. The above methods differ mainly in the type of extracting solution, concentration, buffer capacity, pH value, procedure for making the test, and method of expressing the results. In order to have a comparable expression of the results, the readings in p.p.m. were made by using a 5-ml aliquot of the soil extract that was made for each test method according to directions.

COMPARISON OF PHOSPHORUS AND POTASSIUM TESTS

Standard stock solutions containing known quantities of phosphorus were prepared to be used with each quick testing method. The procedure was as follows: Into volumetric flasks containing the respective extracting solutions exact quantities of mono-potassium-phosphate were introduced which were sufficient when brought to volume to make solutions containing 0.25, 0.50, 0.75, 1, 2, 5, and 10 p.p.m. of phosphorus. The calibration of the blue color was then made by taking a 5-ml aliquot of each of the standard phosphorus solutions, developing the color according to recommended procedure, and comparing the color intensity with a standard color chart to determine the concentration in p.p.m. of available phosphorus.

The common characteristic of the available phosphorus test methods is the Deniges' (5) colorimetric reaction. These methods all employ an acid extracting solution varying in pH from 1.0 to 4.8. The composition of the extracting solutions vary considerably and some have base exchange properties in addition to the solvent action, while others are primarily dependent upon the solvent action of dilute acids. Minor variations were noted in precipitating reagents used with the different tests, but apparently had no appreciable effect on the results.

For the potassium tests, solutions were prepared in a manner similar to that used in preparing those for the phosphorus tests. Potassium chloride was used to supply potassium in concentrations of 10, 20, 35, 50, 75, and 100 p.p.m. The potassium from a 5-ml aliquot of the stock solutions was then precipitated according to the procedure recommended for potassium.

Some modification of the sodium cobalti-nitrite method for the estimation of available potassium is used in all of the rapid tests used in this investigation. The di-potassium sodium cobalti-nitrite ($K_2NaCo(NO_2)_6$) is precipitated by the addition of either ethyl or iso-propyl alcohol and the turbidity is checked against color charts or by the obscurement of standard width lines. A comparator similar to the one used in the LaMotte portable test kit was graduated in p.p.m. by recording the height of the column where each respective concentration of potassium completely obliterated the black line. The sensitivity of this test diminished very

rapidly in the lower concentrations making potassium difficult to estimate when present in quantities as low as 20 p.p.m.

In some of the soils, a modification was necessary to free the filtrate of ammonia. A separate portion of the filtrate was tested with Nessler's reagent and, if an appreciable amount of ammonia was present 1 ml of 37% formaldehyde was added to the soil extract before the alcohol was added and the p.p.m. determined. The formaldehyde combines with the ammonium salts to form hexamethylenetetramine and thus prevents its interference with the potassium test.

All potassium extracting solutions have many similar characteristics varying in pH value from 3.27 to 4.8 and are dependent upon base exchange reactions for the removal of potassium. The LaMotte and "lac-hi-potash" tests which are commercial products appear to be of the same general type. The symbols used to indicate the p.p.m. of the available nutrients were arbitrarily assigned for convenience. The phosphorus symbols are: Very low, 0 to 0.25 p.p.m.; low, 0.25 to 0.75 p.p.m.; medium, 0.75 to 2 p.p.m.; high, 2 to 5 p.p.m.; very high, 5 p.p.m. and above. The symbols for available potassium were as follows: Very low, 10 to 25 p.p.m.; low, 25 to 35 p.p.m.; medium, 35 to 75 .pp.m.; high, 75 to 100 p.p.m.; very high, 100 p.p.m. and above.

YIELDS

The yields used in this study for correlating growth response to fertilizer application are the 1937 yields and average yields secured from respective plats for entire length of the experiment.

The Gaffney experiment on Cecil sandy loam consisted of three series of 35 1/20-acre plats, cotton appearing on one of the series every year. The yields of seed cotton are averages of all years for the experiment. Likewise the Greer experiment on Cecil sandy clay loam consists of 35 1/15-acre plats and each fertilizer treatment is repeated in each of three series. The yields are expressed as either the 1937 yield or as an average for all years of the test.

The Pee Dee experiment on Orangeburg fine sandy loam consists of 43 1/10-acre plats. Each fertilizer treatment is repeated in each of three series of plats. The yields of seed cotton are for 1937 and also a 9-year average from 1929 to 1937.

RESULTS OF PHOSPHORUS TESTS

The results from the fertilizer experiment on Cecil sandy loam located at Gaffney are given in Table 1. The data show that each of the rapid test methods indicated approximately the same amount of available phosphorus for identically fertilized plats. When expressed on a p.p.m. basis, there is very little difference in the amount of available phosphorus on plats which received high and low amounts of this element. The yields show a gradual increase in pounds of seed cotton per acre when the phosphorus content of the fertilizer was raised from 0 to 12%, although the 6 and 8% phosphorus applications gave no increase over their preceding increment, yet the yields were substantially higher than on the 4–0–2 plat. This was more evident in the 1937 yields and the 4–8–2 gave the maximum yield of seed cotton. Apparently the fixing power of this soil for phosphorus, together with the increased absorption of phosphorus by the plants in the production of the higher yields of seed cotton, was sufficient to prevent the accumulation of available phosphorus. The phosphorus

obtained by the Truog-Myer method was significantly higher than that shown by the rapid tests and appeared to be associated with the percentage of phosphorus in the fertilizer application.

The results from the fertilizer experiment on Cecil sandy clay loam located at Greer are included in Table 1. This soil type is usually more productive than Cecil sandy loam. In this experiment each of the rapid test methods gave approximately the same amounts of available phosphorus on each plat irrespective of fertilizer treatment. A larger amount of available phosphorus for the Truog-Myer method was found in the plats which had received the higher application of phosphorus fertilizer. The Universal, Simplex, and LaMotte methods gave similar results for the variously treated plats, while the Purdue and Bray methods showed higher concentrations of available phosphorus. Here again no significant differences were found in the amounts of available phosphorus from the plats which received high and low amounts of this element.

Apparently the fixation of phosphorus by the soil and the increased crop growth resulting from the addition of phosphorus in the fertilizer mixture accounted for the lack of available phosphorus. The 1937 yield data substantiated the fact that phosphorus is needed on this soil type for maximum production. The data indicate that the amount of available phosphorus in Orangeburg fine sandy loam at the Pee Dee Station is higher than that in the Cecil sandy loam and the Cecil sandy clay loam. The plats on this soil had received an abundant annual phosphate application since 1914. The Truog-Myer method showed a higher concentration of available phosphorus for the plats receiving large amounts of phosphate than for those receiving small amounts. The 1937 yields show that the additional increment of phosphorus in the fertilizer above 4% gave lower returns for the increase rate of the application. Although the 4–12–4 gave the highest yield, it gave an increase of 62 pounds of seed cotton over its preceding increment, while the 4–4–4 and 4–6–4 gave 248 pounds and 118 pounds over their respective preceding increment. The cotton yields indicate that the 4–8–4 fertilizer may be used profitably on this soil type. However, the rapid tests show high amounts of available phosphorus present in all plats where the phosphorus applied was over 6%.

In general, the results from the rapid tests for phosphorus were not in close agreement on this soil type. The Purdue and Bray methods gave consistently higher readings than the other three methods. This was especially true for samples from plats which had received higher applications of phosphorus. Conner (4) acknowledges the inadequacies of the Purdue test. He states "the Purdue test is quite reliable on acid clay and loam soils. It tends to show too high on neutral or alkaline soils on light colored sandy soils and on subsoils". The same criticism is true for soils receiving raw rock phosphate. He gives no explanation of the reason underlying this peculiar feature of the test.

Table 1 also shows the amounts of available phosphorus on Bladen fine sandy loam at the Charleston Truck Station. Unfortunately, all phosphate plats were discontinued before samples were secured and

TABLE 1.—*Comparison of various methods of testing the available phosphorus when expressed as p.p.m. from fertilized plats.*

Fertilizer ratio	Pounds, seed cotton, per acre*		pH of soil	Method of determining available phosphorus											
				Truog		Universal		Purdue		Simplex		Bray		LaMotte	
	Ave.	1937		Lbs./acre	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.
Cecil Sandy Loam from the Gaffney Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre															
0-0-0	288	226	5.18	32	16	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-0-2	491	313	5.51	60	30	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-2-2	731	612	5.37	50	25	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-4-2	847	349	5.30	56	28	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-6-2	787	721	5.51	60	30	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-8-2	853	1,025	5.28	80	40	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-10-2	961	897	5.40	80	40	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-12-2	967	795	5.30	66	33	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
Cecil Sandy Clay Loam from the Greer Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre with the Exception of the Last Treatment which was 1,400 Lbs.															
0-0-0	479	496	5.55	70	35	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-0-2	545	302	5.25	80	40	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-2-2	753	439	5.30	80	40	Low	0.50	Low	0.50	Low	0.50	Medium	1.00	Low	0.50
4-4-2	939	806	5.31	80	40	Low	0.50	Low	0.50	Low	0.50	Medium	2.00	Low	0.50
4-6-2	893	539	5.40	100	50	Low	0.50	Low	0.50	Low	0.50	Medium	2.00	Low	0.50
4-8-2	1,027	907	5.41	120	60	Low	0.50	Medium	2.00	Low	0.50	High	4.00	Low	0.50
4-10-2	1,086	1,041	5.51	125	62	Low	0.50	Medium	2.00	Low	0.50	High	3.00	Low	0.50
4-12-2	1,142	1,168	5.30	130	65	Low	0.50	Medium	2.00	Low	0.50	High	3.00	Medium	1.00
4-10-2	1,408	1,481	5.48	180	90	Medium	1.00	High	3.00	Medium	1.00	High	4.00	Medium	1.00

Orangeburg Fine Sandy Loam from the Pee Dee Fertilizer Experiment; Fertilizer Applied at Rate of 1,000 Lbs. per Acre

0-0-0....	654	497	5.50	36	18	Low	0.50	Medium	2.00	Medium	1.00	Medium	1.50	Medium	1.00
4-0-4....	1,218	1,494	5.48	40	20	Low	0.50	Medium	2.00	Low	0.50	High	3.00	Low	.50
4-2-4....	1,549	1,702	5.50	32	16	Medium	1.00	High	5.00	Low	0.50	High	5.00	Medium	1.00
4-4-4....	1,785	1,950	5.48	70	35	High	4.00	Very high	10.00	High	5.00	High	6.00	High	3.00
4-6-4....	1,894	2,068	5.72	90	45	High	4.00	Very high	20.00	High	4.00	Very high	10.00	Very high	6.00
4-8-4....	2,181	2,329	5.61	160	80	High	5.00	Very high	20.00	Very high	6.00	Very high	10.00	Very high	6.00
4-10-4...	2,144	2,350	5.72	120	60	High	5.00	Very high	20.00	Very high	6.00	Very high	10.00	High	5.00
4-12-4...	2,161	2,412	5.68	170	85	Very high	10.00	Very high	40.00	Very high	10.00	Very high	10.00	Very high	6.00
4-16-4...	1,998	2,047	5.62	180	90	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	High	5.00
4-x-4†...	——	2,118	5.95	728	364	Very high	10.00	Very high	40.00	Very high	8.00	Very high	10.00	Very high	6.00

Bladen Fine Sandy Loam from the Truck Experiment Station; Fertilizer Applied at Rate of 2,000 Lbs. per Acre with the Exception of the Last Treatment which was 1,000 Lbs.

5-7-0, Unlimed.....	——	4.61	250	125	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	Very high	10.00
5-7-5, Unlimed.....	——	4.63	250	125	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	Very high	10.00
5-7-5, Limed	——	5.55	240	120	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	Very high	10.00
5-7-5, Unlimed.....	——	5.40	150	75	High	4.00	Very high	20.00	High	4.00	Very high	10.00	High	4.00

*Unpublished data of the S. C. Experiment Station, Agronomy Department.
†Phosphorus derived from raw rock phosphate.

these tests had to be made on soils from potash plats. The data show high amounts of available phosphorus. The amount of available phosphorus by the rapid tests seem to be in accordance with the available phosphorus as shown by the Truog-Myer method in that more p.p.m. of phosphorus were found on the 2,000-pound application than on the 1,000-pound application. The same extreme differences which were observed in the case of the Orangeburg fine sandy loam are noticed in the results secured from the Charleston samples when the Purdue and Bray test methods were used. They gave higher concentration of available phosphorus than the other tests. The Universal, Simplex, and LaMotte methods gave high readings also, but the p.p.m. agree for all three.

Anderson and Noble (1) in their recent comparison of several rapid test methods found wide differences between them, but believed that the tests may be a valuable aid for trained agronomists in diagnosing soil needs. Morgan (10) made comparisons of the same rapid testing methods, used in the above experiment, on soils treated with phosphate fertilizers from various sources. Discrepancies similar to those found in the present investigation were reported by Morgan for the Purdue and Bray tests. Other irregularities were also found in this investigation with respect to the Simplex and LaMotte methods, as, for example, the results for the raw rock phosphate plats. In this case the LaMotte method gave a very high reading. The Simplex method sometimes gives lower readings than the other methods. On the whole, however, all the methods used give approximately the same results. In these studies the Simplex method gave approximately the same p.p.m. as the Universal and LaMotte methods.

It is concluded from these studies that for South Carolina soils and conditions either the Universal, Simplex, or LaMotte method may be helpful in supplementing existing information for making fertilizer recommendations for phosphorus requirements of soils. However, it is suggested that instead of using small aliquots of the filtrate as directed in some of the tests that the quantity of filtrate for the final reading be increased to 5 ml and the reading made in comparison with permanent color standards or with calibrated color charts.

RESULTS OF POTASSIUM TESTS

Table 2 presents the exchangeable and available potassium as determined by base exchange and rapid testing methods on Cecil sandy loam soil, on Cecil sandy clay loam, on Orangeburg fine sandy loam, and on Bladen fine sandy loam. The amount of replaceable potassium is expressed in M. E. per 100 grams of air-dry soil.

For the Cecil sandy loam the replaceable potassium is extremely low, varying from 0.03 to 0.12 M. E., while an appreciable increase occurs in exchangeable potassium where the potash in the fertilizer application was increased. The moderate application of fertilizer, which was at the rate of 600 pounds per acre, evidently did not supply much more potash than was required for the cotton crop. The yields showed very insignificant increases of seed cotton when the fertilizer ratio was changed from a 4–10–0 to a 4–10–4 except on the 4–10–1

plat which may be attributed to an unavoidable soil variation of terraced fields. Low availability of potassium was indicated by the rapid tests and small differences were found in the readings for soil on the plats which received the various amounts of potash fertilizer. The 4-10-4 plat gave a small increase in yield and had a medium reading for available potassium. Likewise this plat had the largest amount of replaceable potassium. The only reading of the rapid tests that may have expressed a doubtful response is the 4-10-4 plat. However, the 1937 yields show no significant differences in yields of seed cotton between the potash and no potash plats, while on the contrary the rapid tests show low availability.

The available potassium content of Cecil sandy clay loam is greater than on the Cecil sandy loam which is evidenced by the readings of the rapid tests. Likewise, the replaceable potassium content was considerably higher. Thus the rapid tests are capable of showing increases in potassium.

The yields of seed cotton on Cecil sandy clay loam show that potash fertilizer is responsive in stimulating cotton production. The plats that received the 4-10-1, 4-10-2, and 4-10-3 plats produced 94, 127, and 192 more pounds of seed cotton, respectively, than the no-potash treatment. The 1937 yields show more significant responses from potash fertilizer than the average yields as these same plats gave increases of 101, 204, and 376 pound of seed cotton, respectively, over the 4-10-0 fertilizer treatment. The rapid tests show no difference in available potassium content of the soil on those plats which received the different rates of potash. However, no noticeable difference was expected since the difference in the added potash between 0 and 4% plat amounted to only 24 pounds per acre.

Where the fertilizer application had been increased from 600 to 1400 pounds per acre, the yield was materially increased and some of the rapid tests showed a slightly higher concentration of available potassium. This indicated that the application of 1,400 pounds per acre supplied somewhat more potassium than was required for crop growth resulting in an increase in the reserve or replaceable potassium of the soil. In the recent work by Goss and Prince (6), results of similar trend were secured with the rapid tests on some of the field and cylinder experiments at the New Jersey Experiment Station. They found that all plats fertilized with the larger amounts of minerals gave increases in available potassium corresponding with the quantity of fertilizer used.

According to the rapid tests used in this instance, the available potassium of the Orangeburg fine sandy loam was very low indicating a deficiency of potash in this soil. There had been an increase in yield where the potash in the fertilizer application was raised from 0 to 8%. The highest yield of cotton was received from the 4-8-6 fertilizer. The increases for successive increments drop off very sharply where the potash is applied above 2% in the application, but all increments gave significant increases over the 4-8-0 treatment. As might be expected, however, the highest amount of replaceable potassium was found on the plat which had received the 4-8-8 fertilizer.

TABLE 2.—*Comparison of various methods of testing the available potassium when expressed as p.p.m.*

Fertilizer ratio	Pounds, seed cotton, per acre*		pH of soil	Method of determining available potassium														
				Exchangeable			Universal		Purdue		Simplex		Bray		LaMotte	
	Ave.	1937		M.E./100 grams soil	Lbs./acre	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.
Cecil Sandy Loam from the Gaffney Cooperative Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre																
0-0-0	288	226	5.18	0.03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-10-0	931	838	5.40	0.04	32	16	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-10-1	867	622	5.00	0.05	40	20	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-10-2	957	922	5.40	0.06	46	23	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-10-3	998	1,448	5.21	0.08	62	31	Low	25	Low	30	Low	30	Low	30	Low	25
4-10-4	1,078	907	5.00	0.12	94	47	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
Cecil Sandy Clay Loam from the Greer Cooperative Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre with the Exception of the Last Treatment which was 1,400 Lbs.																
0-0-0	479	496	5.55	0.11	86	43	Medium	40	Medium	40	Low	30	Low	30	Medium	40
4-10-0	908	492	5.40	0.11	86	43	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
4-10-1	1,002	593	5.45	0.14	110	55	Medium	40	Medium	40	Low	30	Medium	40	Medium	40
4-10-2	1,035	696	5.48	0.14	110	55	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
4-10-3	1,100	868	5.50	0.15	118	59	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
4-10-4	954	797	5.39	0.17	133	66	Medium	40	Medium	50	Medium	50	Medium	40	Medium	40
4-10-2	1,408	1,481	5.48	0.19	148	74	Medium	50	Medium	60	Medium	50	Medium	40	Medium	50

Orangeburg Fine Sandy Loam from the Pee Dee Fertilizer Experiment; Fertilizer Applied at Rate of 1,000 Lbs. per Acre															
0-0-0.....	654	497	5.50	0.03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-8-0.....	1,286	844	5.47	0.03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-8-1.....	1,772	1,827	5.55	0.03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-8-2.....	1,903	1,683	5.33	0.06	47	23	Very low	10	Very low	20	Very low	20	Very low	20	Very low	20
4-8-3.....	1,962	1,913	5.56	0.07	55	27	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-4.....	2,024	2,180	5.65	0.08	62	31	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-5.....	2,160	2,254	5.69	0.09	70	35	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-6.....	2,181	2,272	5.50	0.08	62	31	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-8.....	1,947	2,518	5.50	0.12	94	47	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
Bladen Fine Sandy Loam from the Truck Experiment Station; Fertilizer Applied at Rate of 2,000 Lbs. per Acre with the Exception of the Last Treatment Which was 1,000 Lbs. per Acre															
5-7-0, Unlimed...	——		4.61	0.12	94	47	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
5-7-5, Unlimed...	——		4.63	0.22	172	86	Medium	70	Medium	70	Medium	50	Medium	70	Medium	60
5-7-5, Limed.....	——		5.55	0.29	226	113	Very high	150	Very high	150	High	100	Very high	150	Very high	160
5-7-5, Unlimed...	——		5.40	0.14	110	55	Medium	40	Medium	60	Medium	40	Medium	40	Medium	60

*Unpublished data of the S. C. Experiment Station, Agronomy Department.

The results of tests of four plats on Bladen fine sandy loam at the Charleston Truck Experiment Station are also presented in Table 2. Three plats had been fertilized for a period of 5 years at the rate of 2,000 pounds and one plat at the rate of 1,000 pounds per acre of commercial fertilizer. The tests showed that the amount of available potassium was considerably higher in these soils than in any of the other soils tested in this study. The amount of available potassium was greater in the plats which had received the 5–7–5 than in the one which had received the 5–7–0 fertilizer. Both the unlimed and limed plats which had received the 5–7–5 fertilizer had higher amounts of available potassium than the plats fertilized with a 5–7–0 fertilizer. The individual tests showed fairly good agreement for these plats, except that the Simplex method gave a slightly lower reading.

The replaceable potassium content of the Cecil sandy loam, Cecil sandy clay loam, and Orangeburg fine sandy loam soils studied in this experiment and for which yield data are available, varied from 0.03 to 0.19 M. E. per 100 grams of air-dry soil, or from 12 to 74 p.p.m. Yield responses were secured on the plats where the replaceable potassium was within this range. Murphy (11), working on Oklahoma soils, found that crop responses were obtained from application of potash to soil having less than 60 p.p.m. of available potassium while some increased yields resulted on soils having as high as 79 p.p.m. of available potassium.

The five methods used in this study for testing available potassium on the four soil types show similar results. It is therefore concluded that any one of these methods show about the same amount of available potash on soil having identical fertilizer treatment. However, since the majority of the soils used in this investigation had a low supply of available potassium, it might be advisable to investigate the reliability of the methods for testing soils containing larger amounts of available potassium. If the results secured in these tests are indicative of the general condition of South Carolina soils they are in need of potash.

SUMMARY

Comparisons of the Universal, Purdue, Simplex, Bray, and LaMotte tests were made to determine their adaptability for use in testing South Carolina soils.

All readings of the tests were made comparable by using a 5-ml aliquot of the soil extract for reading the results of each test in p.p.m. Each of the tests had been previously standardized by checking against known concentrations of phosphorus or potassium.

The data show that the Universal, Simplex, and LaMott testing methods may be used for estimating the phosphorus needs of soil, but the Purdue and Bray tests are not very satisfactory for this purpose for South Carolina soils.

The results also show that all the methods tested show about the same amount of available potassium on soil having approximately the same M. E. of replaceable potassium. The 1937 yields show that on Orangeburg fine sandy loam a good response for potash fertilizer

was obtained on plats where the rapid tests indicated a low availability. The Cecil sandy clay loam gave significant yield increases for potash fertilization, while a medium amount of available potassium or doubtful response was indicated by rapid tests; whereas, a negative correlation was found between yields and the rapid tests on Cecil sandy loam.

LITERATURE CITED

1. ANDERSON, M. S., and NOBLE, W. M. Comparison of various chemical quick tests on different soils. U.S.D.A. Misc. Pub. 259. 1937.
2. BRAY, R. H. A field test for available phosphorus in soils. Ill. Agr. Exp. Sta. Bul. 24. 1929.
3. ————. A test for replaceable and water soluble potassium in soils. Jour. Amer. Soc. Agron., 24:312–316. 1932.
4. CONNER, S. D. What rapid tests have shown about Indiana soils. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
5. DENIGES, G. An extremely sensitive test for phosphorus and arsenic and its application. Comptes Rendus, 171:802. 1920.
6. GOSS, D. M., and PRINCE, A. L. Results of rapid tests to soils of known fertilizer treatment. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
7. HESTER, J. B. Experiments with rapid chemical soil tests for vegetable crops. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
8. ————. Microchemical soil tests in connection with vegetable crop production. Va. Truck Exp. Sta. Bul. 82. 1934.
9. MORGAN, M. F. The Universal soil testing system. Conn. State Agr. Exp. Sta. Bul. 372. 1935.
10. ————. The variance of methods of testing for phosphorus on soils previously treated with different phosphate fertilizer. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
11. MURPHY, H. F. The replaceable potassium content compared with field response to potash fertilization of some Oklahoma soils. Jour. Amer. Soc. Agron., 26:34–37. 1934.
12. SCHOLLENBERGER, C. J., and DREIBELBIS, F. R. Analytical methods in base exchange investigations on soils. Soil Science, 30:161–173. 1930.
13. SPURWAY, C. H. Soil testing. Mich. Agr. Exp. Sta. Tech. Bul. 132. 1935.
14. THORNTON, S. F., CONNER, S. D., and FRAZER, R. R. The use of Rapid Chemical tests on soils and plants as aids in determining fertilizer needs. Purdue Agr. Exp. Sta. Circ. 204. 1936.
15. THOMAS, R. P. The use of rapid soil tests in the United States. Jour. Amer. Soc. Agron., 28:411–419. 1936.
16. TRUOG, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.
17. ———— and MYER, A. H. Improvements in the Deniges Colorimetric method for phosphorus and arsenic. Ind. and Eng. Chem., Anal. Ed., 1: 136–139. 1929.
18. VOLK, N. J., and TRUOG, E. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26:537–546. 1934.

EFFECTIVENESS OF CONTACT SPRAYS IN THE CONTROL OF ANNUAL WEEDS IN CEREAL CROPS[1]

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SINCE the accidental discovery by the French vine grower L. Bonnet, the control of weeds by herbicides as a quick and labor-saving method has been widely resorted to. The pioneer researches of Korsmo (6)[3] and Rebaté (7) and various trails in Europe and America have brought sulfuric acid, sulfates of copper and iron, arsenic compounds, and other chemicals into prominence as efficient contact sprays. Besides large variations in the efficiency of the different sprays, their effectiveness depends largely on the meteorological conditions prevailing at the time of spraying. Thus, successful results are expected if spraying is carried out in fine weather with favorable temperature and humidity.

The experiments so far reported are of local interest since weather conditions vary widely from place to place, making it difficult to arrive at any definite conclusion. Moreover, little knowledge exists about the use of these herbicides in the tropics where weather conditions differ widely from those obtaining in the temperate regions. To elucidate relevant information pertaining to the problem of the physiology and control of weeds as it relates to the tropics, work has been in progress at the Institute of Agricultural Research at Benares, India, for some time past. In the present paper are described the results of experiments on the effectiveness of a few of the more important contact sprays in the control of annual weeds in a cereal crop. Besides the degree of control, the relation of the yield of the crop to the reduction in weed density, the degree of injury to the cereal crop, the time of spraying, the stage of growth of the weeds, and the souring effect on soil due to sulfuric acid spraying have been studied.

EXPERIMENTAL PROCEDURE

The effectiveness of three sprays, *viz.*, sulfuric acid, copper sulfate, and ammonium thiocyanate, was tested. Three separate experiments on three adjacent fields with an uniform history of crop production and manuring were conducted for the three sprays in randomized blocks replicated four times, the size of the plats being 1/50 acre with borders 2 feet in width between them. Clean seeds of wheat (Pusa 4) were sown in the third week of October of 1936.

The spray solutions were applied at the rate of 100 gallons per acre by means of a Knapsack sprayer. One set of plats was sprayed when the weeds were in the young seedling stage, roughly when the fourth true leaf had developed. The wheat at this stage was nearly 6 to 8 inches in height, but no active tillering had proceeded. The second set of plats was sprayed nearly 2 weeks after the first spraying. On an average six leaves were observed on the weeds while tillers had formed in the wheat.

[1]Contribution from the Institute of Agricultural Research, Hindu University, Benares, India. Received for publication October 31, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 208.

The effect of the sprays were observed on the three more abundant weeds, *viz.*, *Chenopodium album*, *Anagallis arvensis*, and *Euphorbia dracunculoides*. The degree of weed infestation and the control obtained by the various treatments were based on the counts of the number of individuals of these three species in 20 random samples of 1-square foot quadrats in each plat recorded between 2 to 3 weeks after spraying. The differences in density between the control and the treated plats were taken as the measure of weed reduction. Estimates of density in each sample before and after the treatments, although afforded possibilities of greater accuracy in the analysis of the data by the covariance method as was adapted in a previous contribution (9), had to be discarded because of the elaborateness in the collection of data involving much time and labor.

The variance of the estimates of density (number of individuals per square foot) being discontinuous, statistical computations to compare the significance of the different treatments on the reduction in weed density have been confined to the square roots of the numbers of individuals per unit area (9).

DATA AND DISCUSSION

EFFECT ON WEEDS

Data of the three experiments on the control of weeds by sulfuric acid, copper sulfate and ammonium thiocyanate (Tables 1, 2, and 3) indicate that all three weeds were significantly reduced in their densities as compared to the control plants. The degree of reduction, however, varied for the different weeds and the different chemicals depending upon the morphological peculiarities and the relative hardiness of the weed species. Wetting of the tissue and penetration of the spray solutions were difficult to attain in the case of the leaves of *C. album* due to the waxy covering, which explains the lower degree of control in the case of this weed. This necessitates the use of a wetting agent since the effective control of weeds depends primarily upon the quantity of spray solution adhering on the plant tissue.

Of the different treatments, hand-weeded plats have shown the highest reduction in the density of individuals of all the three weed species. A comparison of the square roots of densities per unit area by the critical differences[4] indicate that only in the case of *C. album* hand-weeded plats showed a significant reduction in weed density as compared to the other treated plats. This is apparent since none of the chemicals used has brought about a very high degree of control of this weed. When, however, *E. dracunculoides* was sprayed either with 2.5% copper sulfate solution at the fourth leaf stage (Table 2) or 5% ammonium thiocyanate solution at the later stage (Table 3), the reduction of weed density was not high and, therefore, significant differences with the hand-weeded plats were evident.

Since three separate experiments were conducted for the three chemicals, it is not possible to make a direct comparison of their effects. Although the differences between the effects of the three chemicals are not very striking, sulfuric acid appeared to be more

[4]For comparison of the effects between the different treatments (excluding control), the critical differences obtained after eliminating the data of the control plats are estimated and are taken as the measure of significance.

effective than either copper sulfate or ammonium thiocyanate, while the latter appeared to be better than the former.

The effectiveness of spraying appears to increase as the concentration of the spray solutions is increased (Tables 1, 2, and 3). Such a differential behavior is only apparent since the differences between the treatments are not statistically significant. There is, however, a significant difference in the density of *E. dracunculoides* when 5 and 15% strengths of ammonium thiocyanate solutions are used.

The relation of temperature and humidity to the loss of the spray solution by evaporation has long been recognized. The data on the control of the three weeds by sulfuric acid and copper sulfate show that the effectiveness of these compounds for field purposes is unaltered when the plants sprayed in the morning are exposed to the sun with high temperature and low humidity or when the weeds are sprayed in the evening with temperature and humidity factors less conducive to evaporation, contrary to Aslander's (1) pot culture experiments conducted under controlled conditions. A practical program of weed control by chemicals must take into account these factors, but judging from the present evidence not much of a loss of efficiency may be expected if in winter months spraying is carried out in the morning. Facts have to be empirically determined for the different seasons of the year.

The two stages of the growth of the weeds under study have little significance in the matter of their control. The second spraying failed to bring about any marked difference in the degree of control apparently because both the morphological and the physiological conditions of the plants had not undergone any marked change. With two exceptions when thiocyanate solution was sprayed on *E. dracunculoides* (Table 3), this is true for all the three weeds. Although the two stages of the growth of the weeds did not appear to be of much significance in the matter of their control in the present experiments, delayed spraying must not be advocated since the early stimulus given to the wheat crop in the severe set-back to the associated weeds will carry the crop plants beyond weed competition.

A serious draw back in the chemical control of weeds, however, is the power of regeneration of certain weeds. When only the tip portions are killed, lateral branches from the base near the soil surface are seen to grow profusely in the case of *C. album*. A considerable portion of the stand of this weed is often formed by such regenerated plants. Such regenerations were not usually observed in the case of the other two weed species.

EFFECT ON CROP

A perusal of the data on the yield of wheat for the three experiments (Table 4, 5, and 6) shows that all the treated plats gave higher yield per acre as compared with the control plats, although the differences in the majority of the cases are not statistically significant. Significant increases in the grain yield in the hand-weeded plats were obtained in the experiments with sulfuric acid and copper sulfate. The hand-weeded plats of the copper sulfate series have also given the highest yield (Table 5). The majority of the sulfuric acid

and copper sulfate treated plats do not, however, show a significant increase in grain yield as compared with the control plats (Tables 4 and 5). In the thiocyanate experiments all the treatments produced significantly higher yields except when the lowest concentration of the solution was used (Table 6). This significant increase may be traced to the combined effect of the elimination of weed competition and the extra nutrition provided. That the second factor is potent is corroborated by the increased yield in the plats treated with higher concentrations of this solution.

TABLE 4.—*Yield of wheat when spraying with sulfuric acid for weed eradication.*

Treatment				Weed density, number of plants per sq. ft.			Yield of grain per acre, cwt.
No.	Concentration, %	Stage of growth of weed	Time of application	*C. album*	*A. arvensis*	*E. dracunculoides*	
1	Control	———	———	28.25	12.70	8.45	9.16
2	Hand-weeded	———	———	2.10	0.50	0.35	11.19
3	7.5	4-leaf	Morning	9.80	2.00	1.05	10.81
4	10.0	4-leaf	Morning	8.65	1.30	0.55	11.01
5	12.5	4-leaf	Morning	5.95	1.20	0.90	10.60
6	7.5	4-leaf	Evening	10.60	1.90	0.75	10.86
7	10.0	4-leaf	Evening	9.15	0.90	0.45	10.92
8	12.5	4-leaf	Evening	7.75	0.80	0.65	11.25
9	7.5	2 weeks later	Morning	11.35	1.05	1.15	10.79
10	10.0	2 weeks later	Morning	9.75	0.70	0.85	10.69
11	12.5	2 weeks later	Morning	6.65	0.60	0.35	10.94
Significant difference (P = .05).........							1.814

TABLE 5.—*Yield of wheat when spraying with copper sulfate for weed eradication.*

Treatment				Weed density, plants per sq. ft.			Yield of grain per acre, cwt.
No.	Concentration, %	Stage of growth of weed	Time of application	*C. album*	*A. arvensis*	*E. dracunculoides*	
1	Control	———	———	30.25	14.30	12.60	9.67
2	Hand-weeded	———	———	2.20	1.40	1.10	10.77
3	2.5	4-leaf	Morning	13.54	3.41	4.08	10.42
4	4.0	4-leaf	Morning	11.99	3.11	3.20	10.14
5	5.0	4-leaf	Morning	11.42	2.66	3.47	10.50
6	2.5	4-leaf	Evening	11.66	2.93	2.83	10.19
7	4.0	4-leaf	Evening	10.52	2.49	2.57	10.74
8	5.0	4-leaf	Evening	9.51	2.18	2.30	10.60
9	2.5	2 weeks later	Morning	13.22	3.20	3.34	10.17
10	4.0	2 weeks later	Morning	11.72	2.60	2.10	10.46
11	5.0	2 weeks later	Morning	10.07	2.82	2.46	10.56
Significant difference (P = .05).........							0.834

TABLE 6.—*Yield of wheat when spraying with ammonium thiocyanate for weed eradication.*

Treatment				Weed density, plants per sq. ft.			Yield of grain per acre, cwt.
No.	Concentration, %	Stage of growth of weed	Time of application	*C. album*	*A. arvenis*	*E. dracunculoides*	
1	Control	———	———	42.25	19.36	9.61	9.24
2	Hand-weeded	———	———	2.56	1.21	0.50	10.63
3	5	4-leaf	Morning	18.45	2.67	1.62	10.54
4	10	4-leaf	Morning	16.67	1.64	0.83	12.10
5	15	4-leaf	Morning	14.21	0.64	0.26	12.87
6	5	2 weeks later	Morning	19.31	3.34	2.18	10.67
7	10	2 weeks later	Morning	17.36	2.75	1.46	11.51
8	15	2 weeks later	Morning	14.90	0.91	0.55	12.62
Significant difference (P = .05).........							1 51

It is difficult to evaluate the relationship between the increase in yield and the reduction in the density of weeds. The increased yield on the hand-weeded plats in the sulfuric acid and copper sulfate experiments is significant, since it was on these plats that the competition of the crop plants with the weeds was at its minimum. From the inconsistency in the hand-weeded plats of the thiocyanate experiment it would appear that a reduction in weed density did not necessarily result in a higher yield of wheat. It might be mentioned, however, that the weed densities in the present experiments were not alarmingly large and further evidence should be collected before generalizing on the effect upon crop yield of the elimination of weeds. Among the contributory factors, the specific relation of the different weed species should also be taken into consideration.

The injury done to the crop appeared to depend upon the physiological stage of the growth of the crop and the relative toxicity of the spray solutions. Since toxicity increased with the concentration of the spray solution, the degree of injury also parallelled concentration. The stage of growth of the crop was also an important factor. While young plants with tender leaves were more susceptible to injury, the leaves had greater power of recovery and the longer growing period provided an opportunity for the plant to re-establish itself. With increase in age of the crop, however, the leaf, though not so tender, exposed a larger surface thereby increasing the possibility of greater injury. The record of the time taken for recovery by the crop shows that, when weaker solutions were applied earlier, crop plants took 12 to 15 days to recover, but when higher concentrations of the solutions were used another week elapsed before the plants assumed normal appearance. Greater injury was associated with the application of acid spray. The manifestations of toxicity were also rapid in the plants receiving this spray. Besides the possibility of greater injury to the crop plants, another danger of delayed spraying was the longer time required for the plants to recover.

EFFECT OF ACID ON SOIL REACTION

The question is often raised whether sulfuric acid spraying tends to make the soil "sour". With a view to obtain information on this point data on the soil acidity of the acid-sprayed plats have been collected.

The pH values of the soil from the several plats were determined a week after the first treatments were carried out. Random samples of soils were taken to a depth of 6 inches and were properly mixed to make composite and representative samples. The pH values of the soil suspensions were estimated potentiometrically using the quinhydrone electrode. The data thus obtained were analysed statistically by the analysis of variance method. For the second set of plats receiving the treatments at a later date samples were collected before a week after the spraying was carried out. The mean pH values and their standard errors for each of the treatments before and after spraying were computed, so also the standard errors of the difference of the mean pH values to compare the significance of the results.

A perusal of the data (Table 7) indicate that, although a lowering of the pH values in the treated plats is apparent, the differences with the control or hand-weeded plats are not statistically significant. The standard errors calculated on the pH differences in the case of the plats receiving the acid spray at a later date (Table 8) also point to the same conclusion. Thus there was no significant souring effect on the soil of this locality due to the use of sulfuric acid as a weed killer. The present evidence is consistent with the observations of

TABLE 7.—*Soil reaction after sulfuric acid spray applied at the 4-leaf stage of development of the weed plants.*

Treatment		Mean pH*	Critical difference
Concentration of solution, %	Time of application		
Control	——	5.4	—
Hand-weeded	——	5.5	—
7.5	Morning	5.1	—
10.0	Morning	4.9	—
12.5	Morning	4.8	0.74
7.5	Evening	5.0	—
10.0	Evening	4.8	—
12.5	Evening	4.9	—

*Mean of several pH figures.

TABLE 8.—*Soil reaction after sulfuric acid spray applied 2 weeks later than in Table 7.*

Treatment		pH before spraying	pH after spraying	Difference in pH values
Concentration of solution, %	Time of application			
7.5	Morning	5.5±0.136	5.2±0.072	0.3±0.153
10.0	Morning	5.2±0.084	4.9±0.114	0.3±0.141
12.5	Morning	5.3±0.116	4.9±0.220	0.4±0.248

Brioux (5). Even if there be any slight increase of acidity of the soil soon after the acid spraying is carried out, the remarkable buffering capacity of the plants (10) may be relied upon to adjust such changes, and it may not, therefore, be necessary to apply a heavier dose of lime than that required under ordinary conditions of farming.

SUMMARY AND CONCLUSIONS

Replicated experiments on the control of annual weeds in a wheat field of known history by the use of three contact sprays, namely, sulfuric acid, ammonium thiocyanate, and copper sulfate, indicate that the degree of control differed with the different weeds and herbicides. *Anagallis arvensis* and *Euphorbia dracunculoides* showed higher degrees of reduction than *Chenopodium album*, explainable on the morphological peculiarities and the relative hardiness of the weeds as well as on the quantity of spray solution adhering on the surface, while the herbicides showed effectiveness in the decreasing order of sulfuric acid, ammonium thiocyanate, and copper sulfate.

Contributory factors that apparently aided in the effectiveness of the treatments are the concentration of the herbicides, the time of their application, the stage and development of the plants, the leaf area exposed, and the temperature and humidity of the atmosphere. On a statistical examination of the data, however, significant differences were not observed.

The yield of the grain tended to increase with a reduction in weed density, but the differences with the control plats were not always statistically significant. Spraying with a higher concentration of ammonium thiocyanate solution gave significantly better result because of the addition of extra nutrients besides the elimination of weed competition.

Sulfuric acid spraying did not make the soil sour. The small differences in pH, if any, were not significant.

LITERATURE CITED

1. ASLANDER, ALFRED. Sulphuric acid as a weed spray. Jour. Agr. Res., 24:1065–1091. 1927.
2. BALL, W. E., and FRENCH, O. C. Sulphuric acid for control of weeds. Calif. Agr. Exp. Sta. Bul. 596. 1935.
3. BLACKMAN, G. E. The control of annual weeds in cereal crops by dilute sulphuric acid. Emp. Jour. Exp. Agr., 2:213–227. 1934.
4. ———— and TEMPLEMAN, W. G. The eradication of weeds in cereal crops by sulphuric acid and other compounds. Jour. Agr. Sci., 24:368–390. 1936.
5. BRIOUX, C. Compt. rend. Acad. Sci., 179:74. 1924.
6. KORSMO, E. Unkrauter im Ackerbau der Newzeit. Berlin: Verlag Von Julius Springer. 1930.
7. RABATÉ, E. La destruction de Mauvais Herbes. Paris: Librairie l Academie d Agriculture. 1927.
8. SINGH, B. N., DAS, K., and CHALLAM, G. V. Effectiveness of cultural treatments in the control of weeds. Emp. Jour. Exp. Agr., 5:63–68. 1937.
9. ————, ————. Effectiveness of spraying with fertilizers for control of weeds on arable land. Jour. Amer. Soc. Agron., 30:465–474. 1938.
10. ———— and MITRA, G. P. Plant growth in relation to hydrogen ion changes in its medium. Ind. Jour. Agr. Sci., 7:327–348. 1937.

INHERITANCE OF FLOWER COLOR IN ALFALFA[1]

ROBERT LEPPER, JR., AND T. E. ODLAND[2]

STUDIES on the inheritance of certain characters in alfalfa were begun at the Rhode Island Agricultural Experiment Station in 1929. The chief purpose in mind was the obtaining of strains of alfalfa that would be more suitable to local conditions than those now available. On our naturally acid soils, alfalfa is usually short-lived and often difficult to get established. This is especially so when it is attempted to grow it in pure culture. When grown in mixture with grasses and clovers, it seems to thrive much better. If a strain could be produced that would be better adapted to our soil and climatic conditions, alfalfa would no doubt assume a place of more importance on Rhode Island dairy farms. So far, most of the breeding work with alfalfa has been done in the midwestern states where the crop is better adapted than it is in the eastern United States and where the problems of growing the crop are considerably different.

Selections have been made from a number of varieties and strains of alfalfa. These selections have been selfed for the purpose of obtaining pure breeding material to be used in crossing as well as for the study of the influence of selfing. Selections have been made from Grimm, Canadian Variegated, Hardigan, Ladak, Hansen, Cossack, and a number of yellow-flowered *falcata* alfalfa types. After several generations of selfing, crosses have been made between promising lines in an attempt to combine desirable characteristics in one progeny.

Selfing usually results in reduced vigor in alfalfa. The amount of reduction in vigor has varied a great deal among the different lines. Some lines lost vigor very rapidly and were eliminated after one or two years of selfing. A few lines have apparently maintained their vigor even after three and four generations of selfing.

In connection with studies on winterhardiness, yield of forage, and seed production of these various lines, a study was made also on the inheritance of flower colors. Although the limited amount of material and more or less secondary consideration of this character make definite conclusions impossible, a number of facts have been found that are thought to be worth presenting at this time. Crosses have been made between inbred strains with blue, yellow, and white flowers. The blue- and white-flowered types were of the *sativa* group while the yellow were of the *falcata*.

REVIEW OF LITERATURE

Fryer (2)[3] reports that the haploid number of chromosomes in both *M. sativa* and *M. falcata* is 16. This is an indication that crosses between the species are relatively easy to make and are for the most part fertile.

[1]Published by permission of the Director of Research, Rhode Island Agricultural Experiment Station, Kingston, R. I., as Contribution No. 535. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1938. Received for publication November 23, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 216.

Waldron (7), endeavoring to explain the inheritance of flower color, found dominance entirely lacking in a cross between *M. sativa* and *M. falcata*. He noted the varied colors in the F_2 generation which prevent division into sharply differentiated groups. Both the ratios found in the F_2 generation and seven subsequent segregating F_3 families admitted the possibility of at least three factors governing color.

Burton (1) states that the marked variability in color of flowers in the F_2 progeny of two hybrids between *M. sativa* and *M. falcata* studied make the explanation of its inheritance on the basis of phenotypic counts impossible. The number of pure yellow-flowered individuals, however, indicate that this character is controlled by three factors.

The approach to the normal made by the distribution curves of all other characters considered suggests that the expression of these characters is governed by a number of genetic factors.

Korohoda (4) found the supposition of two or three hereditary factors determining the coloration of the blossoms in the F_3 generation of the hybrid to be inadequate. His results indicate that, in the given case, at least four factors are involved—one of each fundamental coloration—cream, blue, and violet and one or two factors intensifying these colorations.

Stewart (6) states that the significantly lower variability in the progenies with respect to plant height, plant width, stem diameter, leaflet length and width, blossom color, and foliage color as a result of one generation of inbreeding leaves little doubt that alfalfa is much less heterozygous than it was commonly thought to be. He further reports that blossom color segregated widely, the progenies grading from extremely light violet to extremely dark violet. Many of them were practically pure breeding. Even the variegated varieties yielded nearly uniform blossom color in a high percentage of the progenies.

MATERIAL USED

Eleven inbred lines were used in these crosses. These were obtained from the two variegated alfalfas, Grimm and Cossack, and several varieties of the *falcata* group. They were selfed from one to three generations before being used for crossing purposes. Hansen, a white-flowered alfalfa obtained from Professor N. E. Hansen, of the South Dakota Agricultural Experiment Station, was used in some of the crosses, while in others, selfed strains, S–357 and S–359, from Hansen were used. Hansen breeds true for white flower color.

A detrimental effect of inbreeding was noted in the production of albino seedlings in the progeny of inbred lines. Selfed lines generally showed a reduction in vigor and some were lost. There were some outstanding exceptions.

There were also a few striking cases of hybrid vigor. In one instance in a cross between a *falcata* and *sativa* alfalfa the F_1 plants grew to a height of more than 10 feet in the greenhouse. The parents made less than half as much growth (Fig. 1).

TECHNIC USED

Selfing was done by placing a single branch in a muslin-covered circular bag to exclude insects or by placing the entire plant in a wire framework covered with muslin (Fig. 2). The flower clusters were first examined and any tripped members were removed. The hands of the operator were then washed in alcohol to destroy any stray pollen and the flower clusters rolled between the thumb and first finger to cause tripping. The flowers were manipulated every other day, weather per-

mitting, for a month or two. Varied and diversified degrees of ability to set seed were apparent not only in the F_2 generations, but also between the various inbred lines. On the whole, greater numbers of seed were obtained in the greenhouse than in the field.

Two methods were employed for the emasculation of the alfalfa floret. In the field the anthers were removed by directing a jet of water upon them. In the greenhouse both the air suction and the water jet methods were used.

The suction method operates on the principle of the vacuum cleaner. A piece of glass tubing which had been drawn to a fine point over a Bunsen flame, thereby creating a very small opening, was inserted in a rubber tube the other end of which was connected to a small suction pump operated by a small electric motor. When the glass tube was then held over the stamens, the suction efficiently removed the anthers and the pollen.[4]

The water jet method was equally simple. A small jet of water expelled from a hypodermic needle was trained on the anthers of the flower which had been tripped and which was supported on the edge of the thumbnail.

The flower was prepared for emasculation by first cutting off the standard at its point of contact with the wings. Then it was tripped by applying pressure at the base of the keel.

Cross pollination was obtained by applying pollen direct from the stamens of the selected parent plant. Care was exercised to choose well-matured untripped flowers. The anthers from several flowers were applied to the stigma of the emasculated plant to assure pollination. The crossed flower was then covered by a muslin bag supported on a circular frame with a tag attached containing the following data: Female plant, date emasculated, male plant, and the date crossed.

FIG. 1.—Hybrid vigor in F_1 generation.

Little success attended the efforts to make crosses in the field. That the water jet method was not responsible for these failures was demonstrated by the fact that both the suction and the jet of water methods were used in making numerous successful crosses in the greenhouse.

Seeds were placed in concentrated sulfuric acid for 8 minutes, washed thoroughly with water, and dried on paper toweling, or nicked with a razor blade in order to secure uniform germination. The seedlings were started in the greenhouse using inoculated soil in either pots or flats. If the seedlings were to be grown for

[4]The authors are indebted to Dr. H. M. Tysdal for suggesting this method.

study in the greenhouse, each plant was transplanted to a 4-inch pot. Otherwise they were set out in the field when about 6 inches in height and in the latter part of May. During the course of the year the greenhouse plants were sprayed to control frequent infestations of aphids and red spider.

Plants were also brought in from the field in the fall to be used for crossing and for obtaining selfed seed during the winter months. These were placed in 10-inch pots and 5 grams of a 4–8–8 fertilizing mixture were added to each pot.

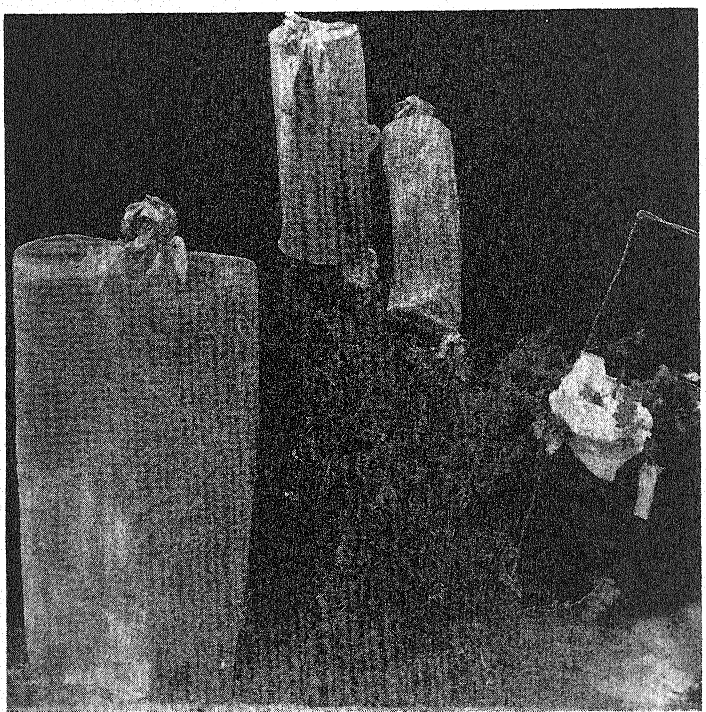

FIG. 2.—Cage and bags used in crossing alfalfa.

Nearly all who have reported work with flower colors in alfalfa have noted the difficulty in making clear-cut distinctions between the various colors and in turn their various shades. The authors, too, were faced with this problem. Colors on the "Old Faithful Tuned Palet" color chart[5] were used as the basis for classification. Each color on the chart was given a number beginning with dark purple as number 1 and ranging to number 20 for white. The flower color notes were taken at the standard petal when a number of blossoms were in bloom in each cluster. It was deemed advisable to combine a number of shades into groups in order to facilitate the inheritance studies. Eight groups were considered sufficient to cover the different color classifications. These were red-purple, dark purple, light purple,

[5]The "Old Faithful Tuned Palet" Color Chart, American Crayon Co., New York.

dark green, light green, yellow-green, yellow, and white. Colors listed in the various tables have been grouped in this manner.

CROSSES INVOLVING PURPLE AND WHITE

Eight crosses were made with inbred Grimm selections as the purple parent and Hansen or selfed progeny of Hansen as the white-flowered parent. In all cases, the F_1 generation had purple flowers indicating a dominance of purple to white. In the F_2 generation these crosses yielded a combined progeny of 411 plants with various shades of purple flowers and 29 white-flowered plants as is shown in Table 1.

TABLE 1.—*Segregation of flower color in Medicago crosses involving purple, yellow, and white.*

Cross	Number of crosses	F_1 flower color	Distribution of flower color in the F_2				
			Purple	Green	Yellow	White	Total
Purple × white...	8	Purple	411	—	—	29	440
Purple × yellow..	1	Purple	38	—	10	1	49
White × yellow ..	1	Purple	23	—	3	15	41
Var. × white.....	1	Purple	127	140	4	2	273

The numbers of purple and white individuals compared with the calculated numbers for a 15 to 1 ratio are as follows:

	Purple	White	Total
Observed...............	411.0	29.0	440
Calculated (15:1).........	412.5	27.5	440

This is a very close fit for these numbers.

Seven F_3 progenies were grown. Three of these were from a selfed purple and four were from selfed white-flowered plants. Only a few plants were obtained from the purple-flowered plants and these were all of various shades of purple. Thirty plants were produced in the four progenies from the white-flowered F_2 plants. All had white flowers indicating that white flower color breeds true after being isolated.

PURPLE BY YELLOW CROSS

The hybrid X10 resulted from a cross between S201, three generations removed from a purple-flowered Grimm selection, and the yellow-flowered S186 one generation removed from a *falcata* (U. S. 24452).

The F_1 flower color was a light purple indicating, as no apparent dominance was recognized in the F_2, that purple is epistatic to, or covers up the yellow flower color.

A small F_2 progeny of but 49 plants was grown, 38 of which were classified as purple and 10 as yellow. One white-flowered individual was found (Table 1).

Considerable difficulty was experienced in classifying these F_2 progenies as about 20% of the plants possessed variegated flowers which changed from purple through green to yellow. Moe (5),

Hagem (3), and Burton (1) also report that this condition caused difficulty in classification. Variegated flowers were apparent in neither parents nor F_1.

Though the F_2 progeny was small and was hardly large enough to warrant that any conclusions with respect to color inheritance be drawn, the wide range of color and the relative numbers of purple, yellow, and white-flowered plants indicated that at least a three-factor difference was responsible.

When the observed numbers are compared with the calculated assuming a three-factor difference with purple epistatic to yellow the following results are obtained:

	Purple	Yellow	White	Total
Observed	38	10	1	49
Calculated (12:3:1)	37	9	3	49
Difference	1	1	2	0

The closeness of this fit suggests that the theory applied is a logical one. None of the yellow plants obtained were identical with the pure yellow of the *falcata* parent. The failure of the pure yellow to appear is assumed to be due to various modifying factors.

Three F_3 progenies were grown. One of these bred true for white while the other two from purple-flowered parents bred true for this color.

WHITE BY YELLOW CROSS

The hybrid X35 resulting from a cross between S359 and S360, the latter a yellow-flowered *falcata* alfalfa one generation removed from U. S. 35312, proved to be of interest as it was a light purple-flowered plant. The occurrence of this purple-flowered F_1 initiated the assumption that a factor for purple color may be carried in the white-flowered parent plant in the presence of the recessive condition of a factor for the production of color.

An F_2 progeny of 41 plants was classified into three groups as regards color. As is shown in Table 1 these were yellow, light purple, and white. The large number of white-flowered individuals in this comparatively small F_2 progeny allows for the assumption of the presence of another dominant factor for the production of color which is supplementary to the first.

The F_2 phenotypic ratio admits the possibility of a three-factor ratio as is evidenced by the following comparison of observed to calculated numbers:

	Purple	White	Yellow	Total
Observed	23	15	3	41
Calculated (36:19:9)	23	12	6	41
Difference	0	3	3	0

Here again the observed compares favorably with the calculated results. F_3 progeny were not grown as selfed F_2 plants failed to set seed.

CROSSES RESULTING IN VARIEGATED FLOWER COLOR

X25 was the result of a cross between Hansen and S206 which was three generations removed from a Cossack selection. Cossack is a variegated alfalfa. The F_1 of this cross showed a very interesting condition as regards flower color. Each floret was dark purple upon blooming, but in the course of a day or two changed to dark green; consequently, there resulted inflorescenses which contained both purple and green flowers.

An F_2 progeny of 273 plants was grown which ranged in flower color from purple through green and near yellow to white (Table 1). It is interesting to note that nearly a third of these plants were of variegated color. This seems to indicate the presence of a single recessive factor for variegated flowers. However, the F_1 showed variegated flowers and appears to have reverted to the characteristic variegated alfalfa from which its purple parent arose. The F_3 progenies further indicate more than a single recessive factor since both solid and variegated flowering plants segregated for this condition.

To facilitate classification, flower color was taken after the color had changed.

The wide color range and the large number of colored plants in proportion to the white suggests the presence of at least four factors.

As is shown in Table 2, seven F_3 families segregated for color, but the variation was not so wide as in the F_2 generation, except where a variegated F_2 plant was the parent. This narrowing of the range of variation suggests that some of the plants already tended towards homozygosity and also that variegated plants were in a heterozygous condition for more factors.

TABLE 2.—*Segregation for flower color in F_3 generation families of the cross F_1–25.*

F_3	Color of F_2	Distribution for color in F_3								Total plants
		Red-purple	Dark purple	Light purple	Dark green	Light green	Yellow-green	Yellow	White	
F_3–25–1	Yellow-green	–	–	7	–	–	1	–	–	8
F_3–25–2	Light purple	–	1	9	–	–	3	–	4	17
F_3–25–3	Yellow-green	–	1	6	–	–	3	4	3	17
F_3–25–4	Yellow-green	–	2	7	–	1	3	–	1	14
F_3–25–5	Light purple	–	–	3	–	–	–	–	–	3
F_3–25–6	Light green	–	2	7	–	–	6	4	2	21
F_3–25–7	Dark purple and dark green	–	1	8	6	1	6	1	–	23

INTERACTION OF FLOWER COLORS

It has been suggested that there appear to be present two dominant supplementary factors which influence the production of color. The absence of both of these factors results in white flowers whether or not

the individual plant carries factors for color. Purple was regarded as epistatic to yellow.

Employing these explanations and letting P represent the factor for purple, Y the factor for yellow, and C and A the supplementary factors for the production of color, the following genetic makeup of the various types was assumed:

Purple	PPCCAAyy
Yellow	ppCCaaYY
White	PPccaayy

On this basis a 15 to 1 ratio of purple to white would be obtained in purple and white crosses; a 12 to 3 to 1 purple-yellow-white ratio in purple by yellow crosses; and a 36 to 9 to 19 Purple-yellow-white ratio in the yellow by white crosses.

Although the numbers are not large and not enough F_3 progenies have been studied to substantiate this hypothesis, the authors would like to present it as a tentative basis for the explanation of the results obtained in these crosses.

LITERATURE CITED

1. Burton, G. W. The inheritance of various morphological characters in alfalfa and their relation to plant yields in New Jersey. N. J. Agr. Exp. Sta. Bul. 628. 1937.
2. Fryer, J. R. Cytological studies in Medicago, Melilotus, and Trigonella. Can. Jour. Res., 3:3–50. 1930.
3. Hagem, O. Some F_2 and F_3 generations of the hybrid *Medicago sativa* and *Medicago falcata*. Hyt Mag. Naturvidenskab., 56:149–165. 1919. (Review in Bot. Abst., 8:222. 1920.)
4. Korohoda, J. Inheritance of certain characters of the hybrid of *Medicago sativa* and *Medicago falcata*. Pam. Panst. Inst. Nauk. Gosp. Wiejsk. Pulawach. 1933. (Mem. Inst. Natl. Polon. Econ. Rurale Pulawy, 14:378–393.) In Polish with English summary. Seen in abstract.
5. Moe, G. G. Alfalfa studies: A preliminary study of the inheritance of certain morphological characters. Unpublished thesis, Cornell Univ. 1928.
6. Stewart, G. Effects of inbreeding on variability in alfalfa. Jour. Agr. Res., 49:669–694. 1934.
7. Waldron, L. R. Vererbung der Blutenfarbe bei Hybriden von Medicago sativa und M. falcata. Pflanzenbau, 6:157–166. 1929.

SOME CHANGES IN THE SOIL DURING NATURAL SUCCESSION OF VEGETATION AFTER ABANDONMENT IN WESTERN NEBRASKA[1]

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THE investigations reported here were part of a study of the natural succession of vegetation on abandoned farm lands in Kimball County, Nebraska. The study was confined to the Rosebud soils, which have been described by Jackson, Hayes, and Weldon (3).[3] Its purpose was to determine some of the changes occurring in the soil during the process of revegetation. Native grassland areas, cultivated fields, and fields abandoned for different periods of time were used. The rate of infiltration of water was observed in the field. The volume-weight, rate of percolation of water, state of aggregation, and organic matter, nitrogen, and root content were investigated in the laboratory.

RATE OF WATER INFILTRATION AND VOLUME-WEIGHT

Areas abandoned 1, 3, and 7 years were used for this study, together with adjacent native grassland and cultivated fields for comparison. In each abandoned area four conditions of vegetation were studied, *viz.*, (a) spots in which the dominant species were grasses, (b) spots in which the dominant species were forbs,[4] (c) spots having a mixed grass and forb vegetation, and (d) bare areas. Where grasses were dominant, the principal species were *Setaria viridis* on land abandoned 1 year and *Bromus tectorum* on land abandoned 3 years. Where forbs were dominant, the principal species were *Salsola pestifer* on 1-year abandonment and *Plantago purshii* on the 3-year abandonment. In the areas of 7-year abandonment, *Agropyron smithii* and *Chenopodium album* were dominant species in the grass and forb areas, respectively.

PROCEDURE

Two cylindrical tubes of brass, 3.867 inches in inside diameter, 6 inches long, and having a wall thickness of 0.0625 inch, were fastened end to end by means of a ½-inch strip of tinned sheet iron encircling the joint and soldered on. One cylinder had a cutting edge which facilitated its entrance into the soil. This composite tube was forced into the soil until the top of the upper cylinder was even with the

[1]Contribution from Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Neb. Published with the approval of the Director as Paper No. 223, Journal Series. A portion of a thesis submitted to the faculty of the University of Nebraska in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication December 12, 1938.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 227.

[4]The term *forb* refers to any non-grasslike herb.

surface.[5] After the removal of some of the soil around the outside, a rubber extension (a band of automobile tire inner tube 3.5 inches in diameter and 2 inches wide) was attached to the brass cylinder, leaving about 1 inch of rubber projecting above the brass to act as a reservoir to hold water.

The first 100 cc of water was added only as rapidly as it would disappear in order to maintain the hydrostatic head at a minimum. Thereafter, the water was added in 100-cc portions, making an initial depth of 1.3 cm above the soil surface. As soon as one addition of water had been absorbed by the soil, the next was added immediately. The exact time required for each 100-cc portion to disappear was recorded until 800 cc, equivalent to approximately 4 inches of water, had been added to each cylinder. After the last portion had disappeared, the rubber band was removed and the cylinder was covered with a close-fitting brass lid. The whole was covered with debris to protect the soil from insolation and loss of moisture.

A period of 72 hours was allowed for excess moisture to drain away. Each cylinder was then excavated, and the lower end of the soil column was cut off flush with the end of the cylinder. The strip of tin-plate was removed by winding it off with a key, and the column of soil was cut in two at the joint between the two 6-inch cylinders by means of a fine wire. The contents of the two cylinders were placed in separate paper bags and set aside to dry. The samples were later used in the determination of volume-weight and root content.

Quadruplicate determinations were made in each area.[6] The results shown in Figs. 1 to 3 represent the average of the four replications. The rate of intake of water was at first very rapid, but became slower after the absorption of 100 to 200 cc (0.5 to 1.0 inch), and remained fairly constant thereafter. There was some tendency for the rate of movement of water to increase after 400 to 600 cc (2 to 3 inches) had been added. This is undoubtedly the result of the lateral spread of water after it reached the unconfined lower end of the 12-inch column.

OBSERVATIONS

VOLUME-WEIGHT

Table 1 shows the volume-weight of the soil samples from the first and second 6-inch depths of the various areas, and the rates of infiltration of water through the 12-inch column. In general, there appears to be a negative correlation between the volume-weight of the surface 6 inches of soil and the infiltration rate. The 7-year abandonment condition has a low volume-weight and a high infiltration rate, while the 1-year abandonment has a high volume-weight and a

[5]For the purpose of forcing the cylinder down, two augers were set into the soil 30 inches apart. A wooden span was placed between these and rested against collars held on the auger stems by set screws. The cylinder was placed, sharp edge downward, midway between the two augers and an automobile jack was set on the top of the cylinder with the top of the jack against the wooden span. The cylinder was then forced down by means of the jack. This method was developed by J. C. Russel, Associate Professor, and Boris Bulatkin, formerly Graduate Assistant, of the Department of Agronomy, University of Nebraska. It leaves the soil in the cylinders undisturbed and permits tests that are comparable to natural conditions.

[6]Russel and Bulatkin recommended 10 or more replications to minimize the errors resulting from cracks, root-channels, textural variability, etc. Time did not permit the taking of such a number of replications, and the results obtained may not be entirely representative.

low infiltration rate. The volume-weights of the 6- to 12-inch samples are comparatively uniform and are apparently not related to the infiltration rate. Water was absorbed by the soil of the stubble fields much more rapidly than by the more compact, less porous soil of the native grassland. The stubble field used for comparison to the 7-year abandoned land which had been severely eroded by wind thus exposing the more compact subsoil proved an exception. It has frequently been observed that the absorption of water is much slower where such conditions occur as the result of erosion.

TABLE 1.—*Volume-weights and infiltration rates of the soils under wheat stubble, native grasses, and three different periods of abandonment.*

Area	Volume-weight, grams per cc		Time required for absorption of 800 cc of water, minutes	Average infiltration rate, inches per hour
	0–6 in.	6–12 in.		
Wheat stubble	1.11	1.23	83	2.98
Native grassland	1.23	1.31	184	1.34
Abandoned 1 year:				
Grasses dominant	1.24	1.38	140	1.78
Forbs dominant	1.30	1.34	726	0.34
Mixed vegetation	1.23	1.37	278	0.89
Bare	1.25	1.35	315	0.79
Average	1.26	1.36	365	0.68
Wheat stubble	1.19	1.40	55	4.48
Native grassland	1.29	1.40	176	1.41
Abandoned 3 years:				
Grasses dominant	1.18	1.32	61	4.05
Forbs dominant	1.26	1.37	136	1.83
Mixed vegetation	1.22	1.35	61	4.05
Bare	1.31	1.36	118	2.10
Average	1.24	1.35	94	2.64
Wheat stubble	1.21	1.37	216	1.15
Native grassland	1.08	1.35	102	2.45
Abandoned 7 years:				
Grasses dominant	1.18	1.38	117	2.12
Forbs dominant	1.06	1.37	65	3.82
Mixed vegetation	1.10	1.35	55	4.51
Bare	1.24	1.38	102	2.42
Average	1.14	1.37	85	2.92

PERCOLATION RATE

When the field work on infiltration of water was completed, the 6-inch brass tubes were coated inside with paraffin and put down in the same 3-year abandoned area as that used for the infiltration study. Triplicate samples were taken from each of the six surface conditions. About 400 cc of water were added, and the cylinders full of moist soil were excavated 2 days later. The soil column was cut off even with the bottom of the cylinder and lids were placed on each end of the cylinder and taped securely to prevent evaporation. In this

manner the soil was kept in an undisturbed field-moist condition until the percolation study could be undertaken.

The procedure used for obtaining percolation rate was as follows: The lids were removed from the ends of the brass cylinder and the bottom of the soil column was covered by filter paper, cheesecloth, and galvanized hardware cloth, successively. The cylinder was placed upright in a funnel which supported the hardware cloth in proper position. On top of the soil column were placed a filter paper and a disc of brass window-screen wire to prevent erosion of the soil when water was added. A band of rubber inner tube was placed around the top of the cylinder, the same as for the infiltration experiment. Six funnels and cylinders were supported in a rack. Fastened to the top of the rack were two small iron pipes. One of these was attached to a vacuum pump and the other to a supply of water. By means of rubber connections and screw clamps, both inflow of water and suction could be regulated as desired. The apparatus maintained a thin sheet of water on the surface of the soil and thus maintained a small constant hydrostatic head.

Graduated cylinders were placed under the funnels to catch the percolate. After the first 50 cc had been discarded, the volume of percolate was recorded each hour for 6 hours. The results are shown graphically in Fig. 4 as averages for the three cylinders from each vegetative condition.

There appears to be a slight negative correlation between the percolation rates and the volume-weights of the soils (Table 1). The native grassland and bare areas, with high volume-weights, permitted the slowest percolation; the mixed vegetation and annual grass areas showed medium to low volume-weights and intermediate percolation rates; and the wheat stubble area, having a low volume-weight, permitted rapid percolation. The forb area, however, had a relatively high volume-weight and also a high percolation rate. The conclusion may be drawn from these facts that the percolation rate is not directly related to the total pore space of the soil but depends also on the size and character of the pores, as suggested by Krause (4). Large continuous cracks and channels permit more rapid percolation, while the small, capillary pore spaces of the native grass and bare areas cause a much slower movement of water.

AGGREGATE ANALYSIS

After the percolation experiments were completed, the soil in the cylinders was used for a study of the state of aggregation. The cylinders of wet soil were placed in contact with dry soil for 24 hours to draw off the excess water by capillary action. The moist soil was then removed from the brass cylinders and screened through a sieve of four meshes per inch. This was done carefully in order to disturb the aggregates as little as possible. After the soil had been thoroughly mixed the percentage of the soil mass present in the form of aggregates larger than 0.5 mm in diameter was determined by the method of Tiulin (8), as described by Rhoades (5). The results, which are the average of determinations on the three cylinders of soil from each vegetative condition, are presented in Table 2.

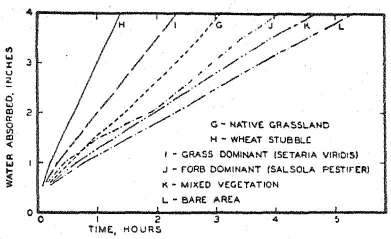

FIG. 1.—Rate of infiltration of water into soil under native grassland vegetation, under wheat stubble, and under different vegetative covers after 1 year of abandonment.

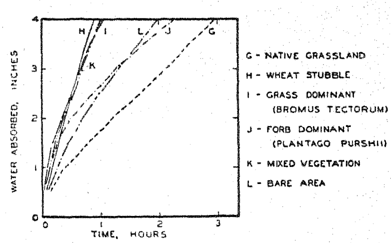

FIG. 2.—Rate of infiltration of water into soil under native grassland vegetation, under wheat stubble, and under different vegetative covers after 3 years of abandonment.

TABLE 2.—*State of aggregation, volume-weight, infiltration rate, and percolation rate of soils under native grasses, wheat stubble, and different kinds of vegetative cover after 3 years of abandonment.*

Area	Aggregates larger than 0.5 mm, %	Volume-weight	Infiltration rate, inches per hour	Percolation rate, inches per hour
Grass dominant	16.3	1.18	4.05	0.43
Wheat stubble	18.8	1.19	4.48	0.84
Forb dominant	21.0	1.26	1.83	0.97
Mixed vegetation	23.4	1.22	4.05	0.49
Native grasses	30.6	1.29	1.41	0.11
Bare area	31.3	1.31	2.10	0.20

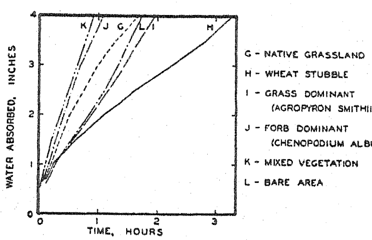

FIG. 3.—Rate of infiltration of water into soil under native vegetation, under wheat stubble, and under different vegetative covers after 7 years of abandonment.

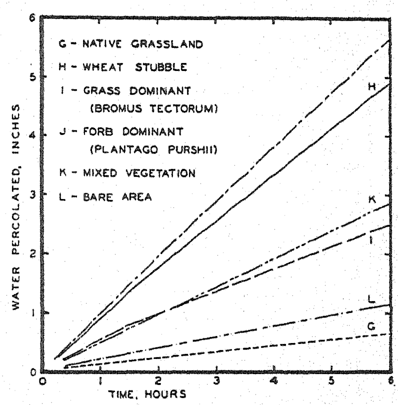

FIG. 4.—Rate of percolation of water through soils from areas under native grasses, wheat stubble, and different vegetative covers after 3 years of abandonment.

The native grassland soil and that from the bare area showed a high degree of aggregation, about 31% of the entire soil existing in the form of aggregates larger than 0.5 mm in diameter. Under the other conditions, the degree of aggregation was lower.

In Table 2 the figures on aggregate analysis are arranged in the order of increasing magnitude to show more clearly the correlation between this characteristic and the volume-weight, the rate of infiltration of water in the field, and the laboratory percolation rate. It is evident from the table that there is a greater proportion of large aggregates in the more compact soils and that water moves through such soils more slowly. In the soils that have been loosened by cultivation, water moves more rapidly, but many of the aggregates have been reduced to 0.5 mm or less in size.

ROOT CONTENT

The soil samples on which infiltration rate and volume-weight determinations were made were used for making comparisons of the root content of native grassland, wheat stubble, and the different periods of abandonment. They were soaked in water for a few hours and then separated from the root material by means of a battery of grain-grading sieves. The finest sieve had openings 2 mm in diameter. The soil was placed upon the coarsest sieve and a jet of water played upon it until only the gravel and root material were left. This process was repeated for each sieve. The combined residues were then washed into a pan of water. The roots were separated from the gravel, oven-dried, and weighed. The average amount of root material in four cylinders for each condition studied is given in Table 3. Since each cylinder had an average inside diameter of 3.867 inches, and a corresponding cross-sectional area of 11.75 square inches, it was possible by means of these data to compute the approximate weight of roots per acre under each of the conditions studied. The results of these calculations also are shown in Table 3. In the final column, the relative root content of each area is expressed on the basis of the corresponding native grassland area as 100. For the 1-year and 3-year periods of abandonment, there is no great difference between the abandoned fields and the stubble fields, all of them having about one-fourth to one-third of the root content of the corresponding areas of native grass. After 7 years of abandonment, the root content had increased to nearly half that of the native grassland. The stubble land corresponding to the 7-year abandoned area is not comparable, however, because wind erosion had removed much of the surface soil. The data indicate that the quantity of root material in the soil under cultivation is much less than under native vegetation, and in the course of several years of abandonment an appreciable increase occurs.

ORGANIC MATTER AND NITROGEN

Composite samples of 10 cores of soil were taken from areas of different periods of abandonment, cultivated land, and native grassland for the determination of organic matter and nitrogen content. These were taken at random and are meant to be representative of average conditions in each area. A tube 2 inches in diameter was used for the 0- to 6-inch depth and a 1-inch tube for the 6- to 12-inch depth.

TABLE 3.—*Weight of root material in the soil of native grassland, wheat stubble, and abandoned areas.*

Area	Roots in four cylinders, grams		Root material per acre, lbs.			Relative root content, native as 100
	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–12 in.	
Native grassland	12.81	2.56	3,770	753	4,523	100
Wheat stubble	3.25	0.20	956	59	1,015	22
Abandoned 1 year:						
Grasses dominant	3.23	0.34	951	100	1,051	
Forbs dominant	3.16	0.39	930	115	1,045	
Mixed vegetation	4.90	0.40	1,442	118	1,560	
Bare	3.48	0.13	1,024	38	1,062	
Average	——	——	1,087	93	1,180	26
Native grassland	11.59	1.94	3,411	571	3,982	100
Wheat stubble	3.88	0.54	1,142	159	1,301	33
Abandoned 3 years:						
Grasses dominant	4.87	0.32	1,433	94	1,527	
Forbs dominant	2.75	0.90	809	265	1,074	
Mixed vegetation	3.80	0.48	118	141	1,259	
Bare	1.18	0.34	347	100	447	
Average	——	——	927	150	1,077	27
Native grassland	9.90	1.44	2,914	424	3,338	100
Wheat stubble	0.46	0.08	135	24	159	5*
Abandoned 7 years:						
Grasses dominant	5.71	1.23	1,680	362	2,042	
Forbs dominant	5.36	0.31	1,577	91	1,668	
Mixed vegetation	6.33	0.20	1,863	59	1,922	
Bare	2.20	0.14	647	41	688	
Average	——	——	1,442	138	1,580	47

*This field had been severely eroded by wind.

The composite samples were dried and screened through a sieve of four meshes per inch. All roots and rhizomes were cut and mixed with the soil without loss. After each sample had been thoroughly mixed, a pint of sub-sample was removed and ground to pass through a 0.5-mm sieve.

Nitrogen was determined by the usual Gunning method (2). Organic matter was determined by a modification[7] of the hydrogen

[7]The Robinson method, as modified by Prof. J. C. Russel, Department of Agronomy, University of Nebraska, is as follows: Arrange a series of uniform 50-cc glass-stoppered weighing bottles in pairs of nearly equal weight. Number them consecutively, giving the lighter one of each pair the odd number. Clean and dry the weighing bottles, remove the stoppers, and allow them to come to hygroscopic equilibrium with the atmosphere. Weigh out on a counterpoised scoop two 2.000-gram portions of air-dry soil (1.000 gram in case of soils containing much over 5% of organic matter, and 0.2000 gram in the case of peat or organic materials), and transfer to two paired weighing bottles. Stopper the bottles as filled. When all samples are weighed out, place the bottles in pairs on the balance, the odd-numbered bottle (the lighter) on the right pan, and the other on the left, and determine to the fourth decimal the difference in their weights. Set the even-numbered bottle aside for the time. Transfer the contents of the odd-numbered bottles to beakers, using a little water to rinse out traces of soil, then set these

peroxide method of Robinson (6). Most of the duplicate samples agreed within 0.001 gram and in cases of differences greater than 0.002 gram new determinations were made. Russel and Engle (7) have shown that the method is reliable and yields results which agree well with those obtained by multiplying the organic carbon content by the conventional factor 1.724. The hygroscopic coefficient was determined by the method of Alway, Kline, and McDole (1).

The results of the organic matter and nitrogen determinations are presented in Table 4. There is such great variation that no definite conclusions can be drawn as to the changes in soil organic matter and nitrogen resulting from cultivation and abandonment. The data appear to indicate a loss of these constituents from the upper 6 inches of soil under cultivation, but statistical analysis shows that the differences are not significant. In the 6- to 12-inch depth the average figures for organic matter and nitrogen are practically identical in native grassland, wheat stubble, and abandoned areas.

By means of the data on volume-weight, total organic matter content, and root content, from Tables 1, 3, and 4, the percentage of root material in the whole mass of soil organic matter may be computed. The results of such computations are shown in Table 5.[8]

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bottles aside. Now add 10 cc of 30% hydrogen peroxide to each beaker, cover with a glass, and digest on a carefully regulated hot plate. From time to time the beakers should be rotated to rinse down the sides. After all of the peroxide has been decomposed, remove the beaker from the hot plate, and if necessary, add 5 cc more of peroxide, rinsing the sides of the beaker with it. Continue the digestion until all of the peroxide is decomposed. 15 cc of hydrogen peroxide used in this way is usually sufficient for all soils, but if incomplete digestion is feared, more should be used. After digestion is complete, scrub the cover glass well with a policeman and rinse into the beaker. Transfer the contents of the beakers to 100 cc centrifuging tubes into which 5 cc of 10% ammonium carbonate solution has previously been placed. Scrub the beakers well with a policeman. The rinsings should not exceed 80 to 90 cc and the tube should finally be filled with a strong jet of water that will mix the contents thoroughly. Cover the beakers and set aside. Allow the tubes to set for a time for flocculation to occur, and then centrifuge until the supernatant liquid is very clear. Pour off the liquid into the original beaker in which the soil was digested and set aside. Agitate the residue with a little water, then rinse it into its original weighing bottle and scrub the tube thoroly with a policeman. With experience and care, the tube can be completely washed without more than once filling the weighing bottle. Place the bottle and lid in the oven and evaporate to dryness, then place beside it the companion bottle containing the moisture sample and continue drying at 110° for at least 8 hours. Cool the weighing bottles in pairs in the same desiccator, and re-determine the difference in their weights. Remove the odd-numbered weighing bottle and weigh the other bottle and contents to the third decimal. Subtract the weight of the bottle to obtain the oven-dry weight of the sample used. Ignite, cool in a desiccator, and weigh to the fourth decimal a series of platinum dishes. Transfer the contents of the beakers to the dishes and evaporate to dryness, then ignite in a medium red muffle furnace for a few minutes, cool in a desiccator, and weigh. Calculate the weight of the ignited residue. To calculate organic matter content, subtract the initial difference from the final difference in weigh-bottle weights, and subtract from this the weight of the ignited residue in the dish. This gives the weight of organic matter in the sample. Divide this weight by the oven-dry sample weight and multiply by 100 to obtain the percentage of organic matter.

[8]The volume-weights of the native grassland and wheat stubble soils are the averages for the three fields of Table 1 and those of the abandoned soils are the average of the four different surface conditions for each period of abandonment. The organic matter percentages are from Table 4, and the weights of root material per acre are from Table 3, the figures for the three native grassland areas were

TABLE 4.—*Soil organic matter, nitrogen, and organic matter-nitrogen ratios in areas of native grass, wheat stubble, and abandoned land.*

Area	Organic matter, %		Nitrogen, %		OM/N ratio	
	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–6 in.	6–12 in.
Native grassland.....	2.42	0.64	0.149	0.098	16.2	6.5
	4.10	2.32	0.224	0.150	18.3	15.5
	3.15	1.04	0.198	0.115	15.9	9.0
	2.91	1.36	0.152	0.098	19.1	13.9
	1.56	1.75	0.097	0.068	16.1	25.7
Average...........	2.83	1.42	0.164	0.106	17.3	13.4
Wheat stubble.......	3.13	0.84	0.199	0.067	15.7	12.5
	3.07	1.47	0.204	0.145	15.0	10.1
	1.75	1.04	0.116	0.097	15.1	10.7
	1.80	1.44	0.112	0.093	16.1	15.5
	3.24	1.66	0.078	0.078	41.5	21.3
	1.85	1.70	0.127	0.141	14.6	12.1
Average...........	2.47	1.36	0.139	0.107	17.8	12.7
Abandoned 1 year....	2.76	1.75	0.175	0.133	15.8	13.2
	2.03	1.52	0.153	0.095	13.3	16.0
Average...........	2.40	1.64	0.164	0.114	14.6	14.4
Abandoned 2 years...	2.00	1.50	0.116	0.104	17.2	14.4
Abandoned 3 years...	2.45	1.63	0.150	0.093	16.3	17.5
Abandoned 4 years...	2.27	0.86	0.132	0.105	17.2	8.2
	1.56	1.26	0.095	0.079	16.1	15.9
Average...........	1.92	1.06	0.114	0.092	16.8	11.5
Abandoned 5 years...	3.11	1.06	0.168	0.106	18.5	10.0
Abandoned 6 years...	2.06	1.08	0.128	0.108	16.1	10.0
Abandoned 7 years...	2.83	1.63	0.170	0.112	16.6	14.6

Under native grassland vegetation 7.3% of the "soil organic matter" in the surface soil and 2.2% of that in the second 6 inches was found to consist of root material. These figures compare favorably with those of Weaver, Hougen, and Weldon (9), who found that in the surface 6 inches 8.5 to 10.6%, and in the second 6 inches from 2.8 to 3.8% of the "soil organic matter" consisted of plant roots and rhizomes in native grassland meadows at Lincoln and Union in eastern Nebraska. The cultivated and abandoned lands, however, had a much lower percentage of root material in the soil organic matter. This may be considered as evidence of the incorporation into the soil mass of a much smaller amount of root material than under the native grasses.

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averaged, but those for the wheat stubble area for comparison with the 7-year abandonment were omitted because of wind erosion in this field, and the other two fields of wheat stubble were averaged. As in case of the volume-weights, the figures for each period of abandonment were the average for the four vegetation conditions.

TABLE 5.—*Relationship between root material and soil organic matter in the soil of native grassland and wheat stubble areas and of fields abandoned for 1, 3, and 7 years.*

Area	Volume-weight		Weight of soil, thousands of lbs. per acre		Organic matter, %		Organic matter, lbs. per acre			Root material, lbs. per acre			Root material in soil organic matter, %		
	0–6 in.	0–12 in.	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–12 in.	0–6 in.	6–12 in.	0–12 in.	0–6 in.	6–12 in.	0–12 in.
Native grassland....	1.20	1.35	1,631	1,835	2.83	1.42	46,160	26,060	72,220	3,365	583	3,948	7.29	2.24	5.47
Wheat stubble......	1.17	1.33	1,590	1,808	2.47	1.36	39,270	24,590	63,860	1,049	109	1,158	2.67	0.44	1.81
Abandoned 1 year...	1.26	1.36	1,712	1,848	2.76	1.75	47,250	30,120	77,370	1,087	93	1,180	2.30	0.31	1.53
Abandoned 3 years..	1.24	1.35	1,685	1,835	2.45	1.63	41,280	29,910	71,190	927	150	1,077	2.25	0.50	1.51
Abandoned 7 years..	1.14	1.37	1,549	1,862	2.83	1.63	43,840	30,350	74,190	1,442	138	1,580	3.29	0.45	2.13

Calculation of the ratios of organic matter to nitrogen in the surface soils of the native grass, wheat stubble, and abandoned areas, and of the standard errors of the mean ratios of the three groups of samples, failed to indicate significant changes in the organic matter-nitrogen ratio of the soil in either the first or second 6-inch depth as a result of cultivation or abandonment. If changes have occurred, a larger number of samples from each area would be needed to reveal them.

SUMMARY

A study was undertaken on cultivated land, native grass land, and land abandoned for various periods of time in Kimball County, Nebraska, for the purpose of discovering the changes that occur in the soil during the process of revegetation. Determinations were made of the rate of infiltration of water in the field and of percolation in the laboratory, the volume-weight, the state of aggregation, and the quantity of plant roots, organic matter, and nitrogen in the soil.

The rate of infiltration of water in the field was considerably greater under wheat stubble than under native vegetation. It was relatively low after 1 year of abandonment, but after several years became approximately equal to that of the wheat stubble land. Bare areas in the abandoned land generally had a low infiltration rate.

The rate of percolation of water through a 6-inch column of topsoil showed about the same relationships as the infiltration rate. Percolation in the soil from the native grassland and the bare areas of the abandoned land was much slower than in that from the stubble field and the abandoned areas under vegetative cover.

The volume-weight and the state of aggregation of the soils were very closely correlated. The volume-weight and the percentage of large aggregates (larger than 0.5 mm) were highest in the soils having the lowest infiltration and percolation rates and were generally lowest in the soils permitting the fastest infiltration and percolation.

The root content of the soil of the cultivated fields, determined shortly after wheat harvest, was found to be one-fourth to one-third of that under native grassland vegetation. After several years of abandonment, the root content of the soil was greater than in cultivated fields and was approximately half of that under native grasses.

The organic matter and nitrogen content of the soil of cultivated and abandoned fields tended to be lower than in the native grasslands, but the difference was not statistically significant for the number of samples taken.

Under the native grasses 7.3% of the soil organic matter in the surface 6 inches and 2.2% of that in the second 6 inches was found to consist of plant roots. Under cultivation or abandonment, the percentage of root material was much smaller.

LITERATURE CITED

1. ALWAY, F. J., KLINE, M. A., and McDOLE, G. R. Some notes on the direct determination of the hygroscopic coefficient. Jour. Agr. Res., 11:147–166. 1917.
2. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and tentative methods of analysis. Ed. 4. 1935. (Page 5.)

3. JACKSON, M. L., HAYES, F. A., and WELDON, M. D. Some chemical and morphological relationships between soil profiles of the Rosebud and associated soil series in southeastern Kimball County, Nebraska. Soil Sci. Soc. Amer. Proc., 2:437–445. 1937.
4. KRAUSE, M. Russian investigations in the field of soil structure. Landw. Jahrb., 73:603–690. 1931.
5. RHOADES, H. F. Aggregate analysis as an aid in soil structure studies. Amer. Soil Survey Assoc. Bul., 13:165–169. 1932.
6. ROBINSON, W. O. The determination of organic matter in soils by means of hydrogen peroxide. Jour. Agr. Res., 34:339–356. 1927.
7. RUSSEL, J. C., and ENGLE, E. B. The organic matter content and color of soils in the central grassland states. Proc. 1st Intern. Cong. Soil Sci., Com. V, 4:343–349. 1927.
8. TIULIN, A. TH. Some questions on soil structure. II. Aggregate analysis as a means of determining the true soil structure. Proc. Intern. Soc. Soil Sci., 4:51–54. 1929.
9. WEAVER, J. E., HOUGEN, V. H., and WELDON, M. D. Relation of root distribution to organic matter in prairie soil. Bot. Gaz., 96:389–420. 1935.

TOWARD A GRASSLAND AGRICULTURE[1]

P. V. Cardon[2]

DESTRUCTION of grass[3] has so long characterized land use in America, and the movement to restore grass is so recent, that it would be erroneous to state unqualifiedly that this country is adopting a grassland agriculture. It may never be practicable for America to adopt generally the grassland practices of Europe or New Zealand; and there is reason to question the economic feasibility of adopting such practices in certain parts of this country. But that America during the last few years has launched and is supporting movements tending definitely in the direction of a grassland agriculture is plain to every observer. The more I learn of the historical development of grassland agriculture the more I am disposed to feel that America is treading the same course as that followed by other countries a generation or more ago.

America today is definitely grass-minded. But America still lacks the profound grass consciousness which prompts Europeans to take advantage of favorable physical conditions, to grow more and better grass, and to utilize it to better advantage.

Grass-consciousness differs from grass-mindedness. The one may be and probably is an outgrowth of the other, but grass-consciousness is the more profound. Grass-mindedness inspires grass culture for specific purposes, as, for example, a corrective of soil erosion. Grass-consciousness, on the other hand, regards such specific uses of grass as incidental to its primary uses. It is grass *itself* that is important—grass as a farm crop which is worthy of as good land and as intelligent culture as any other crop. Grass is a crop around which to build profitable farm enterprises; it conserves the land, it benefits other crops grown in rotation with it; it is the basis of a type of farming in which the control of erosion, the protection of water-sheds and the improvement of pastures and ranges follow as matters of course. Thus, grass-consciousness recognizes and utilizes the intrinsic, greater value of grass without discounting but automatically providing for the full play of its incidental values. The culture of other crops fits into this grassland background and grassland agriculture emerges.

It is because America has not yet come fully to appreciate grass as a crop worthy of intensive cultivation and thoughtful management, that she must be regarded as only grass-minded. Speaking broadly, she still thinks of pastures as primarily suited only to that land deemed too poor for other crops; she still thinks of pasture improvement as related only to that land now in pasture, with little regard to the possibility of having better pastures on better land, where

[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Also presented in a slightly modified form before the Crops Section of the Society at Washington, D. C., November 17, 1938. Received for publication December 12, 1938.

[2]Principal Agronomist in charge.

[3]As used in this paper the term "grass" is inclusive of the true grasses and of the legumes usually found in meadows and pastures.

they might prove as profitable as most other crops; she still thinks of grazing as merely a process of turning the livestock "out to grass"; she still regards grass as a tool to be used in erosion control instead of regarding erosion control as a resultant of grass establishment and utilization for the value of the grass itself. True, here and there over the country, one finds exceptions to this rule, but they are exceptions.

But America's topsy-turvy thinking with respect to grass is, I believe, becoming a thing of the past. Having come to an appreciation of grass as a valuable resource, we are turning to methods of restoring grass on lands from which we earlier mistakenly ripped the sod. We sense now the value of grass in protecting us from the ravages of drought, wind and flood; as a substitute crop on acres contributing to surpluses of corn, wheat, and cotton; and as a soil-building crop to replace soil-depleting crops. Moreover, we are experiencing in our efforts to restore grass serious difficulties which tend to make us all the more appreciative of grass cover once it is restored. By this route we shall pass in time from grass-mindedness into grass-consciousness.

This is a significant trend, likely to contribute notably toward a solution of current agricultural problems, but capable at the same time of creating new problems possibly as stubborn as some with which we now contend. That more and better grass has a place in American agriculture, I have no doubt. But whatever that place it will be determined in the long run by the extent to which it fits into economic farm practice. Grass culture induced by subsidy, under any program of soil conservation, may prove helpful in meeting emergency situations; but grass culture, to be most helpful to American agriculture through the long years ahead, must be induced by an inner grass-consciousness on the part of farmers themselves.

That is the long-view on grass. In holding it, I intend no undervaluation of current programs, each of which is exerting an influence conducive to wider use of grass in America. But I, for one, feel that all such programs would contribute even more if carried out according to a pattern acceptable to all groups affected by extended grass culture. Stated differently, I feel that what we are now doing with grass could be better done, if conceived and implemented in the light of an accepted grassland philosophy.

That philosophy, however expressed, would take account of at least these assumptions:

1. That the ideal of soil conservation in America will become a fact when farm practice generally accepts and includes in cropping systems grass *as grass* and not as an expedient. For when American farmers become truly grass-conscious they will plant and manage grass in rotation with other crops because they appreciate its intrinsic values. Then, soil conservation, in all its aspects, will follow as a natural consequence.

2. Farmers will accord to grass its proper place in American agriculture when they become convinced that grass culture is economically feasible not only as a dependable source of feed for livestock, but as a soil-improving crop to be reflected in the returns from other crops and as an otherwise legitimate component of cropping enterprises.

3. To this end, all research, educational, and action agencies could well afford to align their forces. In such alignment these forces would view grass culture broadly and with respect to its place in farm practice within wide areas. They would give full consideration to the economy of grass in current use, as well as to its value in preserving soil for future generations of society.

This alignment of forces probably could be effected as the result of joint thinking on objectives. I would look for constructive thinking among soil and crop specialists, but I would look confidently, also, to the animal husbandman, the nutrionist, the economist, the entomologist, and others. And I would look with equal confidence to organized local or regional groups, as county planning boards and conservation districts, from which would come both thought and action by farmers and business men alike. You see I am suggesting no new force, and nothing new with respect to the possible alignment of existing forces. I stress merely the need for a philosophy around which to effect the alignment.

By such procedure the more extensive use of grass in American agriculture would be considered not only from the standpoint of land-use, which is of utmost importance, but also from the standpoint of grass-use in livestock farming. Personally, I see in grassland agriculture no threat but instead a boon to the livestock industry. If there are misgivings, I think they may be viewed hopefully in the light of the experiences of other livestock countries. But in the formulation of grassland programs, potentialities with respect to the livestock industry should and would be fully considered.

Grassland agriculture represents a definite advance toward stabilized agriculture. It is not a reversion to pastoral practices. It cuts across all phases of agricultural production and therefore commands a high degree of managerial ability. It calls for all of the skill usually required in crop production plus the application of that and other skills in the production of crops in rotation with grass. The successful establishment and maintenance of a good grass cover requires skillful application of the best agronomic information available; and there is much still to be learned about the breaking and preparation of sodland for succeeding crops in rotations of which grass is a part. Moreover, the utilization of grass, if it is to be made profitable, requires knowledge of a high order pertaining to animal production. A successful grassland farmer, in other words, must be a very good all-round farmer. That, perhaps, is reason enough for clarifying the major objectives of current grassing programs, for upon the farmer himself their ultimate value to America will depend.

My own feeling, as I have tried to make plain, is that whether we are ready to recognize it or not we are headed toward a grassland agriculture. With this in mind I would frankly adopt grassland agriculture as a worthy goal and seek the suggested alignment of forces to insure its achievement.

LABORATORY TEACHING IN BEGINNING COURSES IN CROPS AND SOILS[1]

R. I. THROCKMORTON[2]

LABORATORY teaching in crops and soils merits consideration at this time because it is essential for the future development of these sciences that advancement in teaching keep pace with advancement in research. If teaching methods do not advance in proportion to advancements in the field of research and if the teaching personnel is not of so high a standard as that of the research staff, ultimately the lack of proper training of our students due to poor teaching will be reflected in the quality of research. The successful teacher must lay the foundation for future attainments in research.

Within the last three decades much progress has been made in the sciences of crops and soils, and in closely related sciences. An enormous quantity of accurate subject matter has been made available through research for the use of the teachers of these sciences. Not only have many new facts been established, but many theories that were accepted as facts two or three decades ago have been found to be untrue. We may well ask whether teaching methods have kept pace with research, or whether, through placing so much emphasis upon research, teaching has been neglected.

In discussing the teaching of beginning courses in crops and soils, consideration should be given first to personnel or the teaching staff, second to the subject matter, and third to the methods of presentation. Of these three, the personnel is of greatest importance. Regardless of the quality of the subject matter or the method of presentation, a course cannot be taught to the best advantage of the students unless the instructor has the personality and other qualifications that are essential for success in teaching. As much emphasis should be placed upon training men for teaching as training them for research.

In general, during the last 20 to 30 years, the best trained, most enthusiastic, most inspiring, and most ambitious men working in the fields of crop and soil sciences have devoted most of their time, energy and thought to research. It is only natural that such men have been engaged in research because in this field there is an opportunity to establish some new fact, to develop a new method, to originate a new variety, or to do any one of many other things that will result in public recognition through technical and popular publications. The teacher, on the other hand, has little or no opportunity to establish new facts or to originate new varieties, or to do other things which will bring him such recognition. He must be satisfied with the development of men and with seeing the men he has trained achieve success. The man engaged in research has more frequent opportunities to enter other fields of activity than does the man who devotes all of his time to teaching. Also, in general, the field of research is

[1]Contribution No. 288 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Presented at the meeting of the Society held in Washington, D. C., November 16, 1938. Received for publication December 20, 1938.

[2]Head of Department.

more remunerative than that of teaching. These factors have caused the better men to prepare for research and to follow this field of activity in preference to teaching.

The staff members of the departments of crops and of soils in many institutions devote part time to teaching and part time to research. In my opinion this is a desirable arrangement, and those so engaged are usually among the best teachers, but all too frequently the individual finds himself trying to serve two masters. His research program is exacting and interesting; he is crowded for time; and, although he meets his classes and presents the subject matter accurately and in an interesting and inspiring manner, he does not have time to study his teaching methods or the methods used by his colleagues. He has a tendency to continue his teaching year after year along the same general plan with improvements in the subject matter, but not in methods. Time does not permit him to make a study of methods. The research ability of the individual who is devoting a part of his time to teaching and a part to research is directed toward the research problem in which he is interested and not toward research in teaching.

The beginning courses in crops and soils should be taught by the best and most enthusiastic teachers of the staff. Such teachers are giving these subjects in some institutions, but all too commonly it is the practice to have these important subjects taught by inexperienced men and in some cases by graduate assistants or senior students. Since many of the students in agriculture get their first and only impression of the field of crops and soils in the beginning course or courses, it is imperative for success that the teaching method or methods in the class room and laboratory be those that will arouse interest. The inexperienced teacher in the beginning courses usually does not have sufficient background to enable him to inspire a large number of students. I do not mean by this statement that the beginning courses should be used for proselyting purposes or as a means of increasing the number of students majoring in crops and soils. They should, however, give the student a definite picture of the entire field of these sciences and stimulate him to further study along the line of each science which applies to his particular agricultural field of endeavor.

There is a closer and more intimate contact between the instructor and the student in the laboratory than in the class room, and for this reason the strongest personalities and most inspirational men should be in charge of laboratory teaching.

Dr. John W. Crist in the PROCEEDINGS of the forty-sixth convention (1932) of the Association of Land-Grant Colleges and Universities, described the type of teachers needed in our beginning courses as follows:

"They must be teachers who can accomplish the subordination of the prevailing material motives of our American youth to the nobler purposes of the quest of truth and true life. They must be teachers possessed of that mysterious power for quickening the young mind, for arousing it to its full capacity and for creative effort, and for endowing it with a refined control over its owner's personal attitudes and activities."

Dean R. L. Watts of Pennsylvania, in a paper at the forty-seventh annual convention (1933) of Association of Land-Grant Colleges and Universities, said, "If the real function of the college is to develop men, then there must be in charge of every class, men of high ideals and high standards, men of courage and strong convictions, men with unblemished characters, men who are willing to sacrifice for students, who are zealous to equip themselves for the most effective place in economic, political and social life."

Dean Watts recognized the basic difficulty in obtaining and retaining good teachers when he said, "Some administrators are disposed to give greater recognition to members of the faculty who are outstanding as research workers than to those who excel as teachers. Unless there is proper recognition by the administration in paying adequate salaries for successful teachers and in promoting them to the academic ranks which they have earned, continuous improvement in instruction cannot be expected."

As long as men can obtain more rapid advancement in salary and in academic rank in research than in teaching, there will be a strong tendency for them to prepare for the field of research. Progress is being made in overcoming this difference and teachers are better prepared and more capable than they were a few years ago, but there is still too much difference in recognition for the best men to be encouraged to enter the teaching profession in preference to entering the field of research. The man who devotes his life to teaching and who is successful in stimulating his students to learn to think and study makes a definite contribution to society and indirectly to research, and he should be rewarded to the same extent as the research man who has made a definite contribution to science.

SUBJECT MATTER

The subject matter for the laboratory in beginning courses in crops and soils should be closely connected with and developed from the lecture and recitation work. There should be a definite relationship between the two, and the laboratory work should supplement the class work. Changes in laboratory work should be frequent enough to keep pace with changes in the class room and with agricultural knowledge and development.

The laboratory courses in crops and soils should have definite objectives and the work should be planned to meet these objectives. In the beginning courses in crops, the student should become acquainted with all of the farm crops and their characteristics, region of adaptation, and uses, regardless of whether or not they are produced in his locality. He should also become acquainted with the standard varieties of the more common crops produced in his region.

The replies received from a questionnaire submitted to the departments of crops and soils show that in 75% of the institutions laboratory exercises in crops consist primarily of a demonstration of principles; while in 20% of the institutions they consist of both a demonstration of principles and technical studies. It is interesting to note that in many of the replies there is indication that most of the labora-

tory exercises in the more advanced courses are largely technical. This is the type of organization that is most valuable in laboratory instruction because most of the students are not ready for the technical studies when pursuing the beginning course and such studies should be primarily in the more advanced courses. The so-called "practical exercises", such as treating seed for the prevention of disease, the inoculation of seed, and the mechanical grading of seed are obsolete in college instruction. They belong in the vocational classes.

The laboratory exercises in the beginning course in soils should be of such a nature as to give the student a general knowledge of the science of soils with a definite practical application. In most institutions, a high percentage of the students do not take the more advanced courses in soils and for this reason the exercises should be planned and conducted to meet the needs of a majority of the students and not the few who will continue the study of soils.

The replies from a questionnaire show that in approximately 60% of the Land-Grant institutions the laboratory exercises in the beginning course in soils consist primarily of a demonstration of principles. In approximately 12% of the institutions the exercises are technical and consist largely of quantitative studies. Dr. L. M. Turk of Michigan State College made the following excellent statement in a letter relative to types of laboratory exercises: "Technical quantitative studies are not desirable for beginning laboratory courses in soils, particularly in those institutions having the quarter system and only one general course in soils. Time will not permit of much of this type of work. I believe it is more desirable for the general agricultural student to perform exercises consisting primarily of a demonstration of principles. At our institution we have many students (sophomores) taking soils who are not capable of carrying out quantitative experiments with any degree of accuracy. In any case, it is a demonstration of principles and these can be ably demonstrated by qualitative or semi-quantitative experiments."

In laboratory courses in soils, as in crops, the tendency is to use quantitative methods in the more advanced courses. In general, such exercises cannot be used effectively in the beginning course.

There has been a decided improvement in the subject matter offered in soil laboratory exercises during the last few years. Many of the exercises formerly used have been found to be obsolete and have been discarded in most institutions. Some of the obsolete exercises are soil mulch studies, determining capillary rise of water, and heat conductivity in the soil.

METHODS OF PRESENTATION

Much improvement has been made in the methods of laboratory teaching. It has been only a relatively short period of time since in most institutions 6 hours or more of the student's time were devoted each week to laboratory work in each crops and soils, and students were required to conduct long, tedious, and monotonous exercises. The laboratory exercises under such conditions meant little to the

student except a task to be completed. Neither has it been long since students were required to write long detailed reports and to make drawings showing minute details on the exercises performed. At the present time, in more than 80% of the institutions replying to a questionnaire, a period of 3 hours or less is devoted each week to laboratory work in the beginning courses both in crops and in soils. Two institutions reported that no time is devoted to laboratory work in soils, but in one of these cases the beginning course in soils is taught by means of a combination of lecture, recitation, discussion, and demonstration methods.

An attempt was made through the questionnaire method to obtain information on the relative merits of individual participation and the demonstration methods of teaching laboratory courses in crops and soils. The replies received indicate that relatively few institutions have attempted to use the demonstration method in teaching the laboratory course in crops. In the laboratory course in soils, it is a common practice to use a combination of the two methods. In most cases where the demonstration method has been tried it is considered to be superior to the personal participation method for certain types of exercises and inferior for other types. At Ohio State University the demonstration method is used in teaching laboratory courses in both soils and crops and is thought to be superior to the personal participation method.

Written reports on laboratory exercises are not required in soils by about 27% of the institutions, while only 18% do not require such reports in crops. It is interesting to note that practically all of the institutions have discontinued requiring detailed drawings in connection with the reports.

It has been our experience, especially in teaching the laboratory course in soils, that it is more effective to give a short written quiz each week covering the exercises of the preceding week than to require written reports. This method has not only been found to be more effective but also to result in a saving of time for the instructor and the student. I believe, that with certain exceptions, such as field trips and a few special exercises, the instructor is not justified in requiring written reports on laboratory exercises in the beginning courses in either crops or soils.

It is commonly thought that the use of drawings in connection with laboratory reports causes the student to be more accurate and more observing. Dr. H. C. Sampson of Ohio State University, after conducting considerable research on this subject, made the following statement: "We have not found the elimination of drawing exercises to detract either from the amount or the accuracy of observation by the student."

It is fully realized that the preceding suggestion of decidedly reducing the requirements for written reports on laboratory exercises is a distinct departure from the method now in use. I recommend the use of the short quiz method at least as a partial substitute for the written reports. Advantage must be taken of every opportunity to improve our teaching methods. Dr. W. L. Burlison of the University of Illinois states in the PROCEEDINGS of the forty-third annual con-

vention of the Association of Land-Grant Colleges and Universities, "No finer advice on this has come our way than the thought left us in 1897 by Whitman: 'Let us here take warning of one danger to which we are all liable—the danger of adopting ideals and adhering to them as finalities, forgetting that progress in the model is not only possible, but essential to progress in achievement. . . . The head may thus become stored with a lot of fixed mental furniture, and the possessor become the victim of an illusion, from the charms of which it is difficult to disenchant him. He falls into admiration of his furniture, taking most pride in its unchangeableness. It was, perhaps the best to be found in the market at the time of installment, and he finds pleasure in the conceit that what was the best is and must remain the best. He sees new developments in the market, but his pride and inertia content him with the old. The illusion now takes full possession of him, and every departure from his ideals seem like abandonment of the higher for the lower standard of excellence. His conceit grows instead of his ideals, and every annual ring added to its thickness renders it the more impervious'."

Methods used in teaching the laboratory in the beginning courses in crops and soils need serious consideration especially with regard to requiring the student to acquire certain technic in the laboratory. A large percentage of the students taking such courses will not become technical men in either field and the time required for them to learn certain technic is largely wasted. The time available for such courses is limited and can be used to better advantage in other ways than developing technics. This is not true in the case of the more advanced courses where the students are specializing in a particular field and need to acquire the technics of their field of study.

The instructor needs to have clearly defined objectives of what he wishes to accomplish. If he wishes the student to acquire skills, then the student must conduct many exercises individually in order to obtain these skills. However, if he wishes the student to obtain a broad knowledge and understanding of the subject and to learn how to apply that knowledge, a large amount of individual participation in the laboratory should not be necessary. There is a tendency, when using the individual participation method of teaching laboratory courses, for the instructor to exact certain technics without thought of the possible value of such technics to the student during the remainder of his formal education or in after life. I believe the instructors in crops and soils have gone much farther in the elimination of technic development in the beginning courses than have the instructors in most related sciences as botany, zoology, and bacteriology, although in some institutions this type of laboratory procedure has been almost entirely eliminated in the teaching of these basic sciences.

There is ample research evidence available to show that in beginning courses in basic sciences the demonstration method of teaching in the laboratory is superior to the individual participation method, and I can see no sound reason why the results of the research studies in teaching of the basic sciences will not apply to the teaching of crops and soils. Dr. John Dewey made the following statement relative to the methods used in laboratory teaching and of the types of

exercises frequently used: "Our attention may be devoted to getting skill in technical manipulation without reference to the connection of laboratory exercises with a problem belonging to the subject matter. There is sometimes a ritual of laboratory instruction as well as of heathen religion."

I do not wish this discussion to be interpreted as meaning that I think there is no place for written reports and for the individual participation method of instruction in teaching the laboratory in beginning courses in crops and soils. I should, however, like to have it interpreted as a challenge of whether we have definitely established specific objectives in our laboratory teaching, whether the objectives established are correct in view of the fact that most of the students will not continue in the field of either crops or soils, whether the laboratory exercises are of the character they should be to meet the objectives, and whether we have applied scientific studies to our teaching methods to the same extent as we have to our research problems in crops and soils.

SOME RESEARCHES IN EDUCATION AT THE UNIVERSITY OF MINNESOTA[1]

H. K. Wilson[2]

THE first institutions of higher learning in the United States were more or less reserved for the use of wealthy individuals. Not many of the poorer classes aspired to attend a university. The development of the land grant colleges revolutionized the entire system of higher education. Today with the opportunities afforded through the National Youth Administration, scholarships, prizes, and various student subsidies, every boy or girl of average intelligence may hope to attain society's mark of distinction, the bachelors degree.

With the increased attendance in our universities, new curricula were developed. Demands for specialized types of training increased. No longer was it enough to know to parse Latin and Greek; practical information was demanded. As with all major educational movements there was a decided tendency to swing too far to the left. There were those who argued that a farm boy did not need training in economics, psychology, or similar social science courses. In other words, all that should be taught a boy were the manipulative devices enabling him to make money. It did not occur to many that perhaps there were advantages in university training other than learning a vocation.

Today at the University of Minnesota there are more than 15,000 full-time students, ranking it as the third largest educational institution in the country. When one considers the vast number of young people involved, he wonders how well the University is meeting the challenge raised by increased enrollments. Should all of these young people follow a set curriculum? No one believes they should, but there are many who believe the various curricula should be rather rigid without too many loopholes for the student with ideas of his own. The problem of the fixed curriculum is but one of the many confronting our educational institutions today. There are numerous problems relating to increased efficiency in teaching. It is some of these that are discussed here with regard to experimental work at the University of Minnesota as efforts are made to raise the standards of instruction.

THE MINNESOTA COMMITTEE ON EDUCATIONAL RESEARCH

The University of Minnesota has been studying its own problems in a systematic way since about 1919. The first agency to be set up was known as the Survey Commission, and one of its first problems

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Published with the approval of the Director as Paper 384 of the Misc. Journal Series. Presented at the meeting of the Society held in Washington, D. C., November 16, 1938. Received for publication December 3, 1938.

[2]Agronomist. The author wishes to express his appreciation to Dr. E. M. Freeman, Dean of the College of Agriculture, Forestry, and Home Economics, and to Dr. Palmer O. Johnson, Professor of Education, for their valuable assistance in the preparation of this paper.

was a study of the probable growth in student enrollment at the University in the next 25 years. When Dr. L. D. Coffman became President in 1921, other studies were undertaken dealing with such problems as faculty-load, university income and expenditures, etc. In 1921, a Committee on Student Personnel was appointed. While this committee was temporary, one of its recommendations was that a permanent committee should be set up to study educational problems. This recommendation was followed and in 1924, President Coffman created the Committee on Educational Research, a committee which has been continuously active since its initiation.

The membership of the Educational Research Committee consists of 13 persons, drawn largely from the deans of the several colleges and a small group of interested professors. The committee holds no allegiance to any college administration or to any faculty. Its function has been to study the problems of the University, including administrative, instructional, and student personnel problems, and to publish the findings. A large and impressive list of publications has been issued from this source (14, 15, 16).[3]

Briefly stated the procedure in the investigation of a problem consists in the interested college, department, or individual proposing the problem and requesting the cooperation of the committee for financial aid and technical assistance. If accepted by the committee, the request for the necessary funds is submitted to the President of the University for his approval. If the request is granted, the problem is attacked jointly by the sponsoring agency and the technical assistant from the committee, a man trained in the methods of educational research and capable of assisting in laying out the plan of investigation and in collecting, analyzing, and interpreting the data.

During the entire 14 years since its appointment the committee has functioned in furthering educational researches based upon scientific modes of attack. It is to some of these researches that I shall refer.

REVIEW OF RESEARCH STUDIES MADE

In order that I may illustrate the wide range of educational investigations undertaken, let me briefly refer to a few of the pertinent studies made by various members of the University staff.

Koos (11), who studied the junior college movement, noted its rapid development during recent years. He states that the aims of the junior college are to do the first two years of college work satisfactorily, to give pre-professional work, to give occupational training to those not going farther in school, to popularize higher education, and to integrate better the high school and senior college.

Hudelson (5), in a study of class size at the college level, used for his investigations 59 experiments involving 108 classes under 21 instructors in 11 departments in 4 colleges of the University of Minnesota. He compared 6,059 students (4,205 in large classes, 1,854 in small classes) with man-to-man comparisons of 1,288 pairs of students, matched as to intelligence and scholarship. Forty-six,

[3]Figures in parenthesis refer to "Literature Cited", p. 248.

was a study of the probable growth in student enrollment at the University in the next 25 years. When Dr. L. D. Coffman became President in 1921, other studies were undertaken dealing with such problems as faculty-load, university income and expenditures, etc. In 1921, a Committee on Student Personnel was appointed. While this committee was temporary, one of its recommendations was that a permanent committee should be set up to study educational problems. This recommendation was followed and in 1924, President Coffman created the Committee on Educational Research, a committee which has been continuously active since its initiation.

The membership of the Educational Research Committee consists of 13 persons, drawn largely from the deans of the several colleges and a small group of interested professors. The committee holds no allegiance to any college administration or to any faculty. Its function has been to study the problems of the University, including administrative, instructional, and student personnel problems, and to publish the findings. A large and impressive list of publications has been issued from this source (14, 15, 16).[3]

Briefly stated the procedure in the investigation of a problem consists in the interested college, department, or individual proposing the problem and requesting the cooperation of the committee for financial aid and technical assistance. If accepted by the committee, the request for the necessary funds is submitted to the President of the University for his approval. If the request is granted, the problem is attacked jointly by the sponsoring agency and the technical assistant from the committee, a man trained in the methods of educational research and capable of assisting in laying out the plan of investigation and in collecting, analyzing, and interpreting the data.

During the entire 14 years since its appointment the committee has functioned in furthering educational researches based upon scientific modes of attack. It is to some of these researches that I shall refer.

REVIEW OF RESEARCH STUDIES MADE

In order that I may illustrate the wide range of educational investigations undertaken, let me briefly refer to a few of the pertinent studies made by various members of the University staff.

Koos (11), who studied the junior college movement, noted its rapid development during recent years. He states that the aims of the junior college are to do the first two years of college work satisfactorily, to give pre-professional work, to give occupational training to those not going farther in school, to popularize higher education, and to integrate better the high school and senior college.

Hudelson (5), in a study of class size at the college level, used for his investigations 59 experiments involving 108 classes under 21 instructors in 11 departments in 4 colleges of the University of Minnesota. He compared 6,059 students (4,205 in large classes, 1,854 in small classes) with man-to-man comparisons of 1,288 pairs of students, matched as to intelligence and scholarship. Forty-six,

[3]Figures in parenthesis refer to "Literature Cited", p. 248.

TABLE 2.—*Achievement of students in general farm crops with and without previous preparation in general botany 4–5–6, fall quarter, 1927.*

With botany				Without botany			
Student's No.	Honor point ratio	Botany test score	Achievement test score	Student's No.	Honor point ratio	Botany test score	Achievement test score
1	0.916	57	99	1	1.540	8	99
2	0.769	123	96	2	2.151	0	97
3	0.949	27	93	3	0.352	0	91
4	1.674	73	87	4	1.454	14	89
5	1.068	78	86	5	2.096	3	88
6	0.031	26	79	6	0.785	7	85
7	0.376	9	67	7	0.357	0	85
				8	−1.000	0	78
				9	0.166	0	61
M	0.826	56.1	86.7		0.878	3.6	85.9
S.D.	± .483	±36.3	±10.1		± .96	±4.8	±10.5

TABLE 3.—*Retention of botanical knowledge as indicated by correct responses to test items classified in the several botanical categories.*

No. of students	Botany 4–5–6		Comparative morphology	Histology	Algology	Cytology	Taxonomy of flowering plants	Mycology	Physiology	Bacteriology	Genetics
	Year taken	Months after completion									
126	1927–28	Freshmen	1.9	4.4	2.4	2.9	10.7	14.5	11.1	39.5	22.2
29	1926–27	0	78.1	72.9	76.9	75.3	77.9	85.7	86.2	87.3	82.8
24	1926–27	3	41.4	36.5	36.9	31.7	58.6	64.6	65.2	86.2	86.2
29	1925–26	15	18.2	19.9	23.6	29.5	39.2	47.8	51.5	82.2	82.8
22	1924–25	27	12.1	18.7	19.6	24.4	39.5	45.1	49.5	81.5	95.5
No. of test items........			70	50	26	25	72	15	33	6	1

It is believed that these scores are modified largely by the courses following botany. For example, as the courses following botany gave little morphology, histology, or algology, the percentage of retention was lower than for groups which were encountered in later courses. Conversely, a student majoring in agronomy would receive more and more training in the taxonomy of flowering plants, plant physiology, and genetics. Likewise, the retention in these phases was greater as indicated.

In detailed studies made in the College of Agriculture of college aptitude and achievement, Johnson (7) concluded that (a) student achievement during the first quarter in college is an excellent index of survival; (b) the achievement records and ability of students who did not plan to graduate were substantially less than for the average of the entire student body; (c) for the group of students studied, the

college aptitude test appeared to be of limited value in predicting what junior college students will do in the senior college; (d) coefficients of correlation between high school percentile ranks and honor point ratios were more reliable than those between the college aptitude test and honor point ratios; (e) those agricultural students receiving all their elementary training in rural schools showed greater achievement than students who had their elementary schooling in villages or cities; (f) students from farm homes had significantly lower percentile ranks, on the college aptitude test, but their achievement equaled or exceeded that of students from the largest cities; and (g) apparently no relationship existed between ability and time spent in study, recreation, or self-support.

The improvement of types of examination is a subject confronting each teacher. If poorly planned, the old true and false test may be of little value and frequently is of less value than the so-called essay or subjective type of examination. A well-planned examination is one which challenges even the best student. Above all, it must be valid and the instructor must take great care that the questions are clear to the student. The writer has used the new types of examinations for several years, never giving the same examination twice. Never yet, have I given an examination which was not faulty. Always, I find it necessary to rule out certain questions because, while they were clear to me, they proved ambiguous to the student. The instructor should always check the answers to learn if the entire class is out of step or not. The instructor who fails to do this will get a real surprise if he checks the examination replies with care.

Dr. Palmer Johnson (8) has reported on tests and examinations used at the University of Minnesota. The examination problem is one which the Committee of Educational Research has studied for several years. The General College of the University has been used as a testing ground for many new ideas in examination procedure.

Under the plan proposed by Johnson (9), a set of examination questions is not the work of one man but of several. In the large classes of the General College, the examination assistant and the instructor prepare the questions. These questions must be approved by a counselor especially trained in education and capable of passing upon the reliability of test procedures. Recently, a fourth individual, a coordinator has been added. The coordinator is a staff member whose job it is to coordinate the various curricula within the college over a period of years. In many cases the questions are submitted to several staff members within a subject matter division to check upon the validity of each question. This may appear unnecessary to one accustomed to handling the entire job alone. However, test results show that it is important that these checks be made if the examination is to be fair to the student and to the instructor alike.

The five general classes of examination questions may be grouped as follows:

1. Typical objective questions. To be scored with a key. These questions include true-false, multiple choice, and other familiar types.

2. Simple-response questions. These questions require the stating or listing of factual data. Examples are "name", "list", and like types.

3. Uniform content, variable response questions. These questions require a phrase or sentence in response. Examples are "define", "illustrate", and "classify".

4. Variable response and variable content. This type of question requires a more elaborate response, allowing considerable scope in the selection of the answer. Examples are "comment on", "interpret", and "state a question and answer it".

5. Miscellaneous questions. This type includes mathematical problems, translation, marking of maps properly, etc.

Among the primary outcomes of teaching a course are (a) giving the student a vocabulary, (b) teaching him principles or other factual information, and (c) training him to apply the principles or other factual information in the solution of situations or problems. In addition, some courses require the development of certain abilities, as the ability to determine properly the market grade of a sample of wheat or hay. Obviously, the examination procedure which gives the clearest picture of the student's ability to meet life's problems is probably the best to use. The more real one can make the question, the more valuable it should prove in measuring the student's grasp of the subject matter in question.

PREDICTION OF ACHIEVEMENT OF STUDENTS IN THE COLLEGE OF AGRICULTURE

In the fall of 1933–34, Dean E. M. Freeman and Dr. Palmer Johnson initiated a study directed at the prediction of achievement of freshmen entering the College of Agriculture, Forestry, and Home Economics. A battery of tests consisting of the cooperative test in algebra, the cooperative test in science, the Johnson science application test, and tests in science, mathematics, and English prepared under the auspices of Dr. Boardman of the University High School were administered to entering freshmen. Scores from these tests, the high school ratings, and the ratings from the college ability tests were used as measures of prediction. The same battery of tests, with the exception of the cooperative test in science, was administered to freshmen entering in 1934–35. From these trials it was found that the high school percentile rank ratings, the Johnson science application test, and the cooperative algebra test constituted the best combination for predictive purposes. The other measures made no independent contributions. Multiple correlations between the combination of the Johnson science, cooperative algebra, and high school percentile rank and honor-point ratios have been obtained for each of the groups studied over the 4-year period at various stages in the college career as follows: (a) The freshmen entering in 1933–34 have been followed through 4 years; (b) the freshmen entering in 1934–35, 3 years; (c) the freshmen entering in 1935–36, 2 years; and (d) the freshmen entering in 1936–37, 1 year.

The findings over the 4-year period have been consistent. A multiple correlation of .72 has been obtained between the measures of prediction and honor-point ratios at the end of the freshmen year.

For each of the last two years, the predictive measures with their corresponding probability values have been placed in the hands of

the advisers of the college for purposes of directing students with respect to their curricular allocation at the time of entrance to the University.

This year the chief problem consists in integrating the total findings from the 4-year study and exhausting the information provided by the observations. Dean Freeman and Dr. Johnson are preparing a bulletin incorporating the principle findings and their uses. It is hoped that this publication may be available within the coming year. A considerable number of inquiries from other colleges of agriculture indicate wide interest in this study, the first comprehensive one of its kind in this field.

As many know, a large mail-order house has granted large sums of money to colleges of agriculture for the purpose of aiding farm-raised boys to secure a university education.

At the University of Minnesota we do not select these boys until after they come to college. We reason that a boy needs to have enough money to make a start. Following this, the scholarships should enable him to remain in school. This plan permits the giving of the Freeman-Johnson predictive tests. On the basis of these tests, it is possible to predict with surprising accuracy the probabilities of a student earning certain marks in college. For example, the tests may indicate that a student has 12 chances in 100 to earn an average grade of B or better. Another student on the basis of his high school record and test scores may have a predictive score of 0 chances in 100 to earn an average grade of B. He may have a reasonable number of chances to make a C average, the required passing grade. The information derived from these tests, together with personal information, makes it possible to grant the scholarships to students who appear most promising. Also, the information is of great value to the adviser when a student encounters difficulties with his courses. The adviser is better able to determine whether the student is a plain loafer or does not have the mental capacity for making a satisfactory record in college.

CONCLUSIONS

The day when the educator and the psychologist alike were apart from the fields of so-called technical education has passed. Frequently these men cooperate with the teacher of sciences in the making of educational studies. Many so-called educational experiments have been casual and often poorly planned observations which led to hasty and ill-advised conclusions. Today, educational problems are being met in a scientific manner. Just as much research ability is required to conduct an adequate and comprehensive research in education as for an adequate study of how to control noxious weeds. The biological scientist must hold his mind open to the possibilities of improved methods of teaching. He should welcome a new idea in education as warmly as the discovery of a new physiologic or genetic principle in crops research. If the research agronomist will but approach educational problems in this manner, then we cannot fail to witness a renaissance in our agronomic teaching.

LITERATURE CITED

1. CHAPIN, F. S. The Significance of Extra-curricular Activities. (In Problems of College Education.) Minneapolis: University of Minnesota Press. (Pages 351–357.) 1928.
2. DIEHL, H. S. Health and scholastic achievement. U. S. Public Health Rpt., 44:No. 50. Dec. 1929.
3. EURICH, ALVIN C. Four types of examinations compared and evaluated. Jour. Educ. Psych., 22:268–278. 1931.
4. HAGGERTY, M. E. Tests for applicants for admission to University of Minnesota Medical School. Jour. Educ. Psych., 9:278–286. 1918.
5. HUDELSON, E. Class Size at the College Level. Minneapolis: University of Minnesota Press. 1928.
6. JOHNSON, PALMER O. Curricular Problems in Science at the College Level. Minneapolis: University of Minnesota Press. 1930.
7. ————. Aspects of Land Grant College Education. Minneapolis: University of Minnesota Press. 1934.
8. ————. The kinds of tests and examinations used at the University of Minnesota. (In Tests and Measurements in Higher Education. Ed. by Wm. Gray.) Proc. Inst. Admin. Officers of Higher Institutions. 1936.
9. ————. Methods used in improving tests and examinations at the University of Minnesota. (In Tests and Measurements in Higher Education. Edited by Wm. S. Gray.) Proc. Inst. Admin. Officers of Higher Institutions. 1936.
10. JOHNSTON, J. B. Tests for ability before college entrance. School and Society, 15:345–353. 1922.
11. ————. Predicting success or failure in college at the time of entrance. School and Society, 19:773–776; 20:27–32. 1924.
12. KOOS, L. V. The junior college movement. New Republic, 36:22–24. 1923.
13. PATERSON, D. G. Improving the examination function in teaching. Bul. Univ. Minn., 31:47–56. 1923.
14. REPORT OF THE COMMITTEE ON EDUCATIONAL RESEARCH FOR THE BIENNIUM 1928–30. Bul. Univ. Minn., 34: No. 7. Feb. 1931.
15. REPORT OF THE COMMITTEE ON EDUCATIONAL RESEARCH FOR THE BIENNIUM 1930–32. Bul. Univ. Minn., 36: No. 1. Jan. 1933.
16. REPORT OF THE COMMITTEE ON EDUCATIONAL RESEARCH FOR THE BIENNIUM 1932–36. Bul. Univ. Minn., 40: No. 38. April. 1937.

SOME EFFECTIVE AIDS FOR AGRONOMY EXTENSION IN MICHIGAN[1]

R. E. DECKER[2]

SOME people think of the extension worker as a teacher whose classroom is the rural community bounded possibly by county or state lines, and our students as those people living within these boundaries who are interested in agriculture. This is a simple way of explaining our duties, but simplicity ends with that explanation—the actual carrying on of extension work is much more complex.

The undergraduate student goes to classes at a definite time, at a definite place, and often with no definite ideas or experience regarding the subject which he is taking under a definite instructor. If the latter fails to make the subject interesting, it will not greatly affect the size of his audience, at least not during that particular term or semester.

The extension worker meets his group at places calculated to suit the convenience of those interested and these meeting places vary in seating comfort, lighting arrangements, temperature, and other conditions which can influence the attention of those in the group. People attending are generally experienced and often have well-established ideas regarding the subject matter to be presented. They are not backward with criticism. If their ideas are erroneous we must tactfully find a common point upon which we can agree and proceed from there to set up a favorable reaction to the correct practice. In short, our aim is to present correct information in such a way that it will encourage folks to go home and make use of it.

In carrying out extension work we cannot hope to reach everybody through our own personal contacts. County agricultural agents can receive the information from us and assist in distributing it within their counties. They in turn can relay information to Smith-Hughes instructors or to individual farmers whom they find willing and capable of conducting meetings in their communities. More will be said about this later.

We hardly dare to expect that we are going to secure 100% action with one presentation of our subject matter. Personally, I am not certain that high-pressure salesmanship which would secure such results is desired with some projects. Although extension workers endeavor to pass out information which has been well proved experimentally, the extension agronomist is often confronted with many situations affected by soil and climate, as well as the different customs of farmers in carrying out cultural practices.

It was pointed out that the conditions under which meetings are held often will influence the results obtained. About 18 years ago the Dairy and the Farm Crops departments at Michigan State College decided that there was a need for a state-wide campaign to acquaint

[1]Contribution from the Department of Farm Crops, Michigan State College, East Lansing, Mich. Also presented at the meeting of the Society held at Washington, D. C., November 16, 1938. Received for publication December 27, 1938.

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people with the benefits of alfalfa and the proper cultural practices to grow the crop successfully. It was decided to conduct this campaign by counties and that the meetings would reach more people and be more effective if they were held on the farms. In general, these were barn meetings and the particular location in the barn was the cow-stable. The farmers left their own work for a couple hours, coming to the meetings without having to take the trouble of changing their clothes. One extension worker gave a talk on the problems confronting the dairyman, while another explained the methods of growing alfalfa. These meetings were very popular, and played an important part in raising Michigan's alfalfa acreage from less than one hundred thousand to well over a million.

An extension meeting where there are questions from the group, as well as the relating of experiences, is always considered ideal and that is precisely what we secured in these barn meetings. It has always seemed to the specialists who have attended these meetings that there was more discussion when these meetings were held under the exceedingly informal conditions described than where held in halls or other more formal meeting places. The alfalfa campaigns are recalled to emphasize the point that the barn meeting proved an effective aid in getting response from the farmers in a great increase of the alfalfa acreage. The nearer we can bring our meetings to the subject under discussion, the easier it is to arouse interest on the part of those in attendance.

During the last three years we have been carrying on another crops project which is in line with the foregoing statement. This is the hybrid corn demonstration. When these were started in 1936 it was evident that the county agricultural agents were already quite busy with the agricultural conservation program, in addition to their other work. It was, therefore, proposed to them that the hybrid corn demonstrations be arranged in cooperation with the Smith-Hughes agricultural schools wherever such schools were interested. The plan as finally worked out was as follows: The Smith-Hughes agricultural teacher selected a boy who was to conduct the cooperative demonstration. Agreement forms were drawn up in which the duties of each of the cooperators, the boy, the agricultural teacher, the county agricultural agent, and the extension specialist in farm crops were outlined, and these agreements were signed by each party and each retained a copy. At first thought this might seem to be a lot of unnecessary procedure, but it seemed well to have such an understanding of the proper relationship of all parties concerned. For my part I was particularly interested in the boy, that he should realize that he had a responsibility and that the others had their part to perform, as well as himself. He agreed to plant the demonstration according to plans furnished him and to harvest it under the supervision of his agricultural instructor. It was agreed that wherever advisable the agricultural instructor and the county agricultural agent would cooperate in holding a meeting at the demonstration plat at time of harvest. If necessary the extension specialist in farm crops would assist at these harvest meetings.

In the first place the hybrids which are furnished are those which in experimental trials have shown some evidence of being adapted to the particular locality. However, we have included some which we knew were not adapted and others which neighboring states were growing along the border. For example, in our southern tier of counties we gave the boys certified northern Ohio and northern Indiana hybrids, as well as the best of the early certified Illinois strains. Wisconsin hybrids were likewise quite generally used. It is our desire to acquaint corn growers with the best hybrids available regardless of where they were developed.

At harvest the usual procedure has been for the Smith-Hughes instructor to have his agricultural students present and in practically all cases the agricultural agent and a representative of the Farm Crops Department of the College have also been there. A 10-rod row of each hybrid is harvested and weighed and samples taken for moisture and shelling percentage determinations. The students and farmers in attendance look over the different hybrids and pass judgment upon them. The "how and why" of hybrid corn is explained, usually by the extension worker from the College. The students take the samples back to their school laboratory and determine the moisture and shelling percentage, the boy who conducted the demonstration makes out reports and forwards one to each of the other cooperators. The extension specialist summarizes all reports and sends this summary to each of the other cooperators.

We started with these demonstrations in the two southern tiers of counties, but they have increased and during this year we had 90 of these planted, held 81 meetings at harvest, in 25 counties.

The interest is increasing in this type of demonstration. Having a different group of students each year, the Smith-Hughes instructor likes to continue the project. Attendance of farmers at the harvest meetings is increasing. In many cases the county agricultural agents want the farm crops specialist present. It will probably be necessary for the agents to conduct many of these harvest meetings themselves in the future, if demonstrations continue to increase in number, and even if they do not increase it is to the agricultural agent's advantage to conduct the meetings to a large extent.

The value of these demonstrations can be summarized as follows: (1) They provide another valuable contact between the farmers and the extension service; (2) they acquaint people with hybrid corn; (3) they show that all hybrids are not good hybrids; (4) they acquaint students with demonstrational methods; (5) these plats, planted over a wide area, give the extension worker a better idea as to range of adaptation of the hybrids and, better still, a good idea as to what the farmer thinks of various hybrids; and (6) they are interesting a number of good boys and their fathers in hybrid seed corn production, as well as stimulating an interest in other projects.

Work quite similar to this is being carried on with the schools with beans.

A valuable aid in meetings other than field meetings is found in pictures. The use of slides has become quite general among extension workers and they are more effective where the pictures have been

taken of demonstrations or crops within the county or state. The colored picture usually is very effective in crops work, is of more interest to the audience than plain black and white, and provides opportunities for demonstrating certain contrasts that do not show in ordinary pictures. The 35-mm camera from which slides or enlarged pictures can be produced seems more suitable for the extension worker who during a field trip can take pictures of a variety of crop projects and at the end of the season can assemble those pertaining to definite projects and use them during the season of indoor meetings. Moving pictures do not so readily lend themselves to this plan and another thing to consider is that we have much competition from excellent moving picture shows. The word "movie" seems to carry with it the idea of entertainment. Needless to say, pictures should be good or not used at all.

Much has been said in the last few years about the discussion meeting and it was pointed out in a previous paragraph that the ideal meeting was where you could get some discussion. We try to have folks feel that the meeting is theirs, but this is at times a difficult thing to do. If we can get people at the start of a meeting in the state of mind where they feel that they are contributing to its success the stage has been well set.

Several years ago we made our first use of a teaching aid generally associated only with class rooms, namely, an examination. This device, used first at district conferences of county agricultural agents and, since then, at numerous farmers meetings has proved not only effective but, contrary to its class room reputation, exceedingly popular.

The test, as we use it, is made up of the objective type of questions or problems either multiple choice, in which a number of answers are given to a question, one of which is correct; or simple statements which are to be checked as "true" or "false".

A mimeographed copy of the complete set of questions or statements is handed to each member of the group at the beginning of the meeting and time is given for each to note or check his answers. Then the leader takes up each problem and uses it as the basis for group discussion of the particular topic involved.

For example, the statement, "Alfalfa is less likely to be injured by close grazing in late October than it is in mid-September"; true in Michigan, provides an excellent lead for a pointed discussion on the fall management of alfalfa, particularly with reference to the fall storage of root reserves to carry the plants through the winter and initiate vigorous growth in the spring.

Similarly, at a sugar beet meeting, the multiple choice statements that "sugar beets should be grown in 18-, 22-, 24-, or 28-inch rows" stimulates considerable argument as to the merit of the various row-widths, and gives the specialist an opportunity to emphasize information which will enable growers better to exercise their judgment when beet planting time again comes around.

Why is the objective test an effective extension teaching aid? First, I should say, is that it is a stimulus to thought right along the lines which the discussion leader wishes to emphasize whether a

group member takes part in the discussion or not. Second, it stimulates argument and discussion in which everybody takes part. Often those who have checked a statement differently than the leader will defend their position. This draws arguments from others in the group. The result is that, at the close of the meeting, everybody has had something to say, the subject matter has been thoroughly discussed, and people leave feeling that they were really a vital part of the meeting, as indeed they were. However, they should not be permitted to leave until there has been placed in their hands a key sheet upon which are the correct answers to each of the questions, along with supporting evidence for those answers.

Thirdly, with the test problems as an outline, the discussion can be very broad and comprehensive without straying off down blind alleys and crooked by-paths that lead nowhere. When discussion wanders it can always be brought back by taking up the next specific problem.

It may be added that discussion has always been so keen at these meetings that about 20 questions or statements will keep interest at high level for 1½ to 2 hours.

It should be emphasized that the questions or problems are not designed to test the individuals who participate, except perhaps for their own information. Their answers are not taken up and checked by teacher. The answers which each individual has given are his personal concern only. The big idea is that here is a sound pedagogical aid to the stimulation of thought and free discussion which is simply bound to bring out a lot of sound information, as well as to develop the personalities of everyone who takes part.

This method is particularly suited for use with groups of people of less than 50 in number and when the meeting is held where tables or desks are available for writing. It was used in two of our counties where farmer local leaders were taking the work back to groups in their communities. The county agricultural agent and extension specialist met the leaders once a month for four months and four projects of our crops program were successfully explained to these people during that winter.

One of the first communities where this method was used is located about 40 miles from the college in a dairy and poultry section. A day meeting was held during each of December, January, February, and March and at each meeting some crops problem was taken up by the "true" or "false" method. The attendance varied from a minimum of 24 to a maximum of 28, and 23 farmers attended every meeting. Incidentally, the last meeting was held during the worst blizzard of the winter and three-fourths of the men walked to the meeting. Also, on this stormy day we had our largest attendance.

The county agricultural agent of one county has requested us to prepare a set of "objective" statements for his five Smith-Hughes agricultural teachers who are going to hold farmers meetings at their schools during the winter. The agricultural agent and a crops extension specialist will meet with all the instructors sometime prior to the meeting and go over the work. Incidentally, considerable care must be used to make sure that the statements used are clear, pointed, and free from catches or ambiguity.

For small groups we feel that this method is effective in sustaining interest and at the same time teaching the subject matter. However, it would be well for anyone who likes to lecture and expects to do most of the talking to leave this method alone.

In our better seed programs we probably have been guilty of forgetting that the folks who can do us much good in disseminating information on cultural practices and varieties are the seed dealers themselves.

For several years in Huron County a chain of elevators has been working with the county agricultural agent and certified seed growers in distributing to their patrons good seed beans and barley. The elevator management is sold on the idea that the commercial grain which the farmers bring in will be no better than the seed which they sow. This fall the county agricultural agent and crop specialist met with managers of another chain of elevators in the same section of the state and within a few years they will be proceeding in the same manner as the company previously mentioned. The county agricultural agents of most counties are in a position to get their seed and fertilizer dealers working together upon a definite program and the extension agronomist should encourage and assist him in doing this work.

In summary, we have found in Michigan that the aids to effective extension work are both material and human. The use of objective tests as a basis for discussion, field demonstrations with schools, employing of pictures, and occasionally charts at indoor meetings might be classed as material aids. Smith-Hughes instructors, in cooperation with the county agricultural agents, and seed dealers can be the human aids that can make our work more thorough.

Extension work, and particularly agronomy extension which must consider soil and climatic problems, presents a challenge which is hardly found in any other type of teaching. We should make use of all assistance possible in meeting this situation and in carrying to our farmers the best information available.

EXTENSION METHODS[1]

D. L. Gross[2]

EXTENSION methods have changed greatly in the past 20 years. Certain methods, applicable today, could not have been used in the formative period of our extension program. The changed attitude of both farm and city people towards the extension service has made possible the use of new methods of approach. In the earlier years, scepticism toward so-called "book farming" was widespread. Cooperators were few and far between. Opposition was open and militant. We have a photograph in Nebraska which illustrates this attitude. It was taken in 1920 in Clay County. It shows one of our county agents posed before a sign which stood at the gateway of a farmstead. It read as follows: "Every tenth agent will be shot. Nine have already been here."

Although this sign was not posted particularly for the edification of county agricultural agents, it did more or less symbolize the feeling of the times toward the extension service. Extension workers found themselves on an uncharted sea with a somewhat uncertain compass. The county agricultural agent, in order to establish himself in his community, necessarily devoted the major portion of his time to personal service work. His annual report listed the number of hogs vaccinated, chickens culled, trees pruned, and bushels of seed treated.

We may today look upon these methods as outmoded, yet it was through this approach that farm people came to visualize the need and the value of an extension program. Without this initial step the acceptance of the program would have been greatly delayed.

Today we try to avoid personal service and predicate our program upon organization, leadership training, and group action. We can do this today only because of the foundations built in the past. We can do it because of the changed attitude of the people, and because we command their respect and confidence. We can do it because farm and city folk alike appreciate the experiment stations, the colleges of agriculture, and the extension service for assistance and guidance given in the solution of their problems. Today we are sometimes overwhelmed by the faith evidenced in our recommendations. Dr. R. D. Lewis made this significant statement before this Society last winter (Jour. Amer. Soc. Agron., 30:180): "It was only a few years ago that we often wondered if anyone would accept our recommendations. Now we must ever think of the results of large groups accepting them." With this changed attitude of the general public and particularly of farm people, the extension service is enabled to carry out a much broader and more effective program.

WORKING WITH GROUPS

Although the extension worker recognizes that his program must be

[1]Contribution from the Department of Agronomy, University of Nebraska, Lincoln, Nebr. Also presented at the meetinp of the Society held in Washington, D. C., November 16, 1938. Received for publication January 3, 1939.

[2]Extension Agronomist.

seasoned with a measure of personal service, he realizes also that his major activities must be with groups if his program is to reach the greatest number, and if it is to attain the desired ends. Such groups may be of many types. They may be simply unorganized farm community educational meetings of the lecture or discussion type, or they may involve result or method demonstrations. On the other hand, they may be organized groups and involve town as well as farm people. The tendency at the present time is to work more and more with the latter type. Unorganized groups have no crystallized purpose. They make no plans, delegate no authority, and accomplishments are dependent upon the independent activity of individuals. Organized groups have a definite purpose. They formulate programs, determine goals, and delegate activities. Such groups, if properly organized or approached, may become an integral part of an extension program. No extension worker can accomplish much by his individual action alone. By inculcating segments of his program into that of organized groups, however, his efforts are greatly multiplied.

One of the outstanding examples of effective group action and yet at the same time one of the simplest is the 4-H Club movement. Here an organization is set up for a definite purpose. Authority and responsibility are delegated to leaders. By this means the efforts of a single county extension worker are multiplied many fold. His teachings are being carried on in an organized way in many communities with a minimum of direct supervision by himself. In a broader way he makes use of other groups. He organizes communities which plan their own programs, select project leaders, appoint committees, and delegate individuals to perform special missions for the group as a whole. Here again the extension worker has created mechanisms which multiply his efforts and which continue to function so long as he keeps them supplied with necessary inspiration. Other types of county groups could be mentioned such as women's clubs, county soil conservation associations, county poultry, dairy, livestock, or crops improvement associations. Not all of these can be made to function in all counties. Unless the inspiration is present to insure continued vitality in such groups, their organization may be detrimental to the program rather than beneficial. Organization of new groups whose activities tend to overlap those already in existence is also unwise. On the other hand, groups already organized for purposes not directly related to extension work are often anxious to inculcate certain phases of the extension program into their own. If approached in the proper spirit, such groups are more than willing to take part in extension programs.

It is in this field that the state extension worker finds his greatest opportunity from the standpoint of group action. He works through organizations which have state-wide or other major interests. Some of these may have a direct interest in agriculture while with others this interest may be indirect only. Reference is made in part to livestock, dairy, poultry, and crop improvement associations. These associations have a direct interest in agricultural problems. To this category might be added some of the federal agencies, particularly the Soil Conservation Service, Smith-Hughes teaching, Farm Security,

and the AAA. In addition, there are insurance firms, farm management companies, and loan agencies which are confronted with many farm management problems. All of these agencies turn naturally to the college of agriculture for assistance. Mention might also be made of civic groups which have state-wide or sectional interests. Newspapers and farm magazines also play an important part in the agricultural field. In some states the state departments of agriculture have certain activities which deal directly or indirectly with farm people.

Wherever the activities of any of these or other agencies deal with farm people, it is important that their programs be correlated closely with that of the extension service. Diverse recommendations as to practices or procedures can only breed lack of confidence in the programs of all groups. Not only is it important, therefore, that there be complete coordination so far as this is possible, but at the same time such correlation will add strength to all programs. Particularly is this true of the extension program. Essentially, many of the problems encountered by these agencies are also those of the extension service. If coordination can be effected, the extension service has in effect gained that many more arms to carry out its aims.

COORDINATION

Nebraska has made an attempt to bring about this coordination. Undoubtedly there are many states where a program of integration has developed to greater extent than in Nebraska. It may be of interest, however, to describe briefly a few of the processes that are under way with the hope that some of the ideas may be suggestive to others. Work with each agency will be discussed separately.

State improvement associations or societies.—In Nebraska the Crop, Livestock, Dairy, and Poultry Improvement Associations and the Horticulture Society are supported partly by dues and fees and partly by small state appropriations. In most instances the extension specialist whose interests lie in each of the separate fields is secretary of the particular association. Thus the program of each extension specialist and that of the association he represents are worked out on a coordinated basis. "Organized Agriculture Week," called "Farmers Week" or "Farm and Home Week" in some states, is essentially a meeting time for all of these and other state agricultural organizations. Each presents its own program for the farmers of the state, the meetings being held at the College of Agriculture during the winter months. The secretaries are largely responsible for the formulation of the programs for these meetings. General programs which carry on throughout the year are formulated by a board of directors for each association. The secretaries are members of their respective boards of directors. The programs of these associations consist principally of the sponsorship of projects which are or become part of the extension program of each specialist. As an example, the Nebraska Crop Growers' Association sponsors and finances seed certification and employs a field inspector who acts, with the cooperation of the extension agronomist, as certification manager. The inspector offices

with the extension agronomist. Procedures are set up by the board of directors subject to the approval of a state certification committee composed of members of the College staff. This committee is appointed by the Dean of the College under provisions of the state certification law.

This Association also sponsors other projects by contribution of funds. At present these are as follows: 4-H and College grain judging teams; pasture-forage-livestock program; state and national exhibits; participation in International Crop Improvement Association affairs; publication of an annual report bearing principally on subject matter material; seed lists, and educational circulars.

State department of agriculture.—Three men are employed by the State Department of Agriculture to carry out educational and organization work in the eradication of noxious weeds under the noxious weeds district law. Each of the men employed was approved for appointment by the Department of Agronomy. The program of these men is worked out cooperatively with the extension agronomists. Publications are handled in the same manner. Routing of the state department men for educational meetings is handled by the extension service through county agricultural agents. The groundwork leading to the organization of noxious weed districts is worked out on a cooperative basis with the extension service. Organization details are handled entirely by the state department men. Thus, an important segment of the agronomy extension program has been greatly expanded by new funds and the addition of competent, well-trained personnel.

Soil Conservation Service.—Arrangements were made in Nebraska for the state coordinator of the Soil Conservation Service to office in the same building as the extension agronomists. The extension conservationist offices with the extension agronomist. Plans for all educational activities are worked out cooperatively between the two services. Technicians of the Soil Conservation Service assist with many of the educational meetings, conservation tours, level schools, etc. Circulars, film strips, motion pictures, and exhibits are prepared cooperatively. It is said that familiarity breeds contempt. In this instance it would seem that a better statement would be, "Close association breeds understanding and a cooperative spirit." The extension program as well as that of the Soil Conservation Service has been strengthened by this unification of approach to the people.

Mortgage Bankers Association.—Firms represented in this Association own much farm land in Nebraska. They employ many agents who act as land appraisors or farm managers or who have duties which bring them in contact with farm problems. They have the management of many tenant-operated farms and thus have much influence in the determination of practices used. Each year the College sponsors a two-day short course for representatives of this Association. Ordinarily, this comprises a one-day field trip and a discussion program at which farm management and valuation problems generally are considered. The extension service takes an active part in the formulation and presentation of these programs. Thus, new emissaries of the extension program are created.

The Nebraska Lumberman's Association.—Each year the extension engineers conduct a series of demonstration schools for the lumbermen of the state. Design and detailed construction methods of approved types of small and major farm buildings are discussed and demonstrated. As a result of this work, lumbermen are in a better position to advise with farmers in their building problems. Enterprising lumbermen in many instances proceeded to build approved types of small farrowing and brooder houses in quantity thus reducing construction costs. A sales campaign placed many thousand of these buildings on farms, thus contributing to the success of the "Hog Lot and Poultry Sanitation" projects of the extension service.

Civic groups.—The Omaha Chamber of Commerce and the United South Platte Chambers of Commerce are cooperating in the promotion of the "Pasture-Forage-Livestock" project of the extension service. The Omaha Chamber provides funds which are used for printing circulars and for transportation of farmers to a pasture clinic in November. This is held in Omaha where about 400 attend each year. Entries in the program are made by the farmers in the spring of the year. Records are kept by the farmers of their pasture, forage, and livestock projects, and on the basis of these records certain individuals are singled out for special recognition. The clinic is followed by a banquet given by the Omaha Chamber at which prizes are awarded.

The United South Platte Chambers of Commerce aside from actively promoting the project in their respective communities also provide funds for a clinic and a banquet at a convenient point. For the state as a whole, from 800 to 1,200 farmers enter this project each year. This program, considering its present scope, could not have been carried out without the aid of these groups. More will be said of this program later.

Newspapers and magazines.—In cooperation with the Omaha World Herald, one of the leading daily newspapers in the state, arrangements were made for the publication of a series of Sunday feature articles prepared by members of the extension staff. These covered all the major farm projects of the extension service. After the series was completed, all articles were published together in pamphlet form. 40,000 copies of this pamphlet were printed and distributed to subscribers and through the offices of county agricultural agents and business firms.

Assistance is given by extension specialists to the Nebraska Farmer and other farm magazines in the preparation of material for special feature issues.

The Nebraska Farmer's Mutual Fire Insurance Journal, published monthly, and reaching many thousands of farmers within the state, has used its columns for the publication in full of some of our extension circulars.

Several extension news stories clear through the office of the extension editor each day, going to both daily and country weekly papers. Stories for country weeklies clear through the offices of county agricultural agents where they are localized before publication.

CORRELATION OF PROJECTS

Another aspect of extension methods has to do with the correlation of the work between the various subject matter specialists. In some instances there are overlapping or complementary projects which need to be worked out together. When an instance of this kind occurs, a cooperative project may be arranged. This has been done in many states. A few illustrations from Nebraska will be outlined briefly.

Pasture-forage-livestock project.—The drouth years in Nebraska not only destroyed or seriously damaged many of the pastures and much of the range land of the state, but they also resulted in greatly reduced livestock numbers in many sections. Grain and hay were scarce and high in price. Range land needed rest. Dry subsoils, extreme heat, and swarms of grasshoppers prevented the establishment of new pastures. These problems could not be attacked effectively by any single specialist, nor could they be handled most effectively by several specialists working independently. The situation required the cooperative efforts of all who could make a contribution. The extension service alone, because of limitation of funds and personnel, could not cope with the problem adequately. With this in view, conferences were held at which all interested specialists and representatives of a number of outside agencies discussed the problems and formulated a program. Each individual or agency was assigned its contribution. A state-wide educational program was the first step, involving recommendations for resting permanent pastures, planting temporary pastures, a greatly increased acreage of drought-resisting forage and grain sorghums, the use of silage for both winter and summer feed, the building of trench silos, and special recognition to individual farmers for outstanding accomplishment. Animal husbandrymen, dairy men, engineers, agronomists, and farm management specialists from both the College and extension staff were drafted for educational meetings. As many as six teams of two men each were in the field at the same time. Three to five meetings were held each day by each team for a period of three weeks. Daytime meetings were held on farms where a trench silo could be shown. One member of the team discussed crops and harvesting and ensiling methods. The other discussed feeding practices and trench silo construction. Meetings were held in all counties where the feed situation was acute.

This project is still in operation. As has been already stated, important contributions are being made by outside agencies which have taken a special interest in the program. In addition to those mentioned, the Nebraska Crop Growers' Association and the Nebraska Livestock Improvement Association made substantial contributions of funds. The success of the project is evident at the present time. Where few silos existed in 1935, now there are few farms without them in the general farming area. The acreage of drouth and grasshopper resistant forage and grain sorghums has increased nearly 10 fold. Livestock is better fed and numbers are increasing. An extra trench of silage carried in reserve can be found on many farms. This project has developed into an outstanding example of the effectiveness of whole-hearted cooperative effort.

Irrigation schools.—The drouth years in Nebraska greatly stimulated interest in irrigation. Three new canal projects have been developed and hundreds of new pump projects have been installed by individual farmers. It is estimated that by 1940, land under irrigation in Nebraska will have been increased by one-half million acres over that of 1934. Many hundred farmers without previous irrigation experience are already being confronted with irrigation problems with which they are not familiar. To meet this problem, a series of irrigation schools was organized by the extension engineers. Realizing that many of the problems involved were agronomic, the extension agronomists were called upon for assistance in conducting these schools. The groups in attendance at these schools were mostly young men between the ages of 20 and 35. Three to five one-day sessions were held with each group. Lessons included (1) use of the farm level; (2) land preparation, including location of canals and field arrangement; (3) use of water; (4) cropping and rotation practices; and (5) special soil problems. Where there was interest in pump irrigation, one lesson was given dealing with wells, pumps, power equipment, etc. These schools have already prevented many costly mistakes and have set up in each of the communities effected a group of men who can be of service to their neighbors in the solution of both engineering and agronomic problems. An expansion of this program is planned for 1939.

Other joint projects.—Several other joint projects might be listed, important among these being the following:

1. Home beautification project. Cooperating specialists: Extension specialists in home management, extension engineer, extension forester, extension horticulturist. This work is carried on through women's delegate groups representing county women's clubs. The husbands of these women also attend.

2. Sewing machine clinics. Cooperating specialists: Extension clothing specialists and extension engineer. Carried out as in (1) above.

3. Poultry and hog lot sanitation projects. Cooperating specialists: Extension animal husbandry, poultry, agronomy, and engineering specialists. Carried out by demonstration meetings.

DEVELOPMENT OF LEADERSHIP

A discussion of extension methods would not be complete without due consideration being given to leadership development. Present-day extension work is built on the principle of local leadership. Without it our programs would collapse. It is important, therefore, that we weave into all our project planning, methods which will develop leadership.

The AAA program has given us a remarkable demonstration in leadership development. It has given us a new conception of the volume of latent leadership. It has uncovered leadership where we thought none existed. It has developed leadership which is now taking an active part in our extension program as well as in other fields. The more intimate contact of this leadership with the extension

service has in most instances changed the attitude of individuals from that of doubt or even open opposition to one of faith in and whole-hearted cooperation with the extension program. This augmented leadership has made it possible for the extension service to extend its program directly to a group of people who in the past have been served but indirectly.

The germ of leadership is instilled first of all by recognition of the individual, whether it be by election or appointment to an office, assignment of tasks, or public recognition for special accomplishment.

Not all individuals will respond to these stimuli. Not all are capable of leadership. Whether or not the individual responds, he has received much personal benefit. Of interest in this respect is a short paragraph in the August 1938 issue of the READERS DIGEST. This paragraph was headed, "The Tonic of Praise." It read as follows: "Praise is not only gratifying—it is the source of fresh energy which can be measured in the laboratory. Dr. Henry H. Goddard, in his years at the Vineland Training School in New Jersey, used the 'ergograph,' an instrument to measure fatigue. When an assistant said to a tired child at the instrument, 'You're doing fine, John,' the boy's energy-curve soared. Discouragement and fault-finding were found to have a measurable opposite effect."

In Nebraska we have certain projects or project phases into which have been inculcated features or methods which have for their purpose the development of leadership, the energizing of individuals to continue with and improve a good piece of work, or to stimulate larger numbers to follow the example of those who are recognized as leaders. These projects or procedures will be outlined briefly.

Recognition for soil conservation.—In Nebraska, as in other states, there are many farmers who have done outstanding work in the maintenance of soil fertility and in the control of erosion. In cooperation with county soil conservation associations, 13 of which are organized in the state, the extension agronomist and conservationist made arrangements for special achievement meetings in 10 counties. These were sponsored locally by the directors of the soil conservation associations, the Soil Conservation Service, and the county farm bureaus. From 5 to 12 farmers who merited recognition for outstanding accomplishment in soil conservation on their farms were selected in each county by committees of the above organizations. Association funds were used to purchase 16-mm colored motion picture film. One hundred to 200 feet of film were used in each county. Pictures were taken of the selected farmers and their families, their farmsteads and livestock, and the various phases of soil conservation work under way on their farms. County and statewide publicity was given as to the time, place, and nature of the achievement meetings. These were held in the evening during the winter months. In most instances the meetings were preceded by a meal for which a small charge was made. In counties where an evening meal was not served, lunch was provided at the close of the meeting. The serving of a meal or lunch at gatherings of this kind is deemed to be of considerable importance. It tends to break down barriers and promotes a feeling of good fellow-

ship. The evening program usually started with entertainment numbers. These were followed by a brief discussion by the president of the association and presentation by him of "Certificates of Achievement" to those selected. The outstanding accomplishments of each recipient were outlined briefly as the certificates were presented. Each certificate bore the signatures of the officers of the association. The certificates were of special design showing cuts of present day conservation methods. The same certificate form was used in all counties, each association paying for the copies used locally. With each presentation the recipient was given an opportunity to reply and to discuss his conservation methods. There probably will be no disagreement with the statement that the remarks of these men were tremendously more influential than one could expect from similar though perhaps more carefully phrased remarks of a specialist.

Following the presentation of certificates, the motion pictures taken locally were shown first and were followed by those taken in other counties. The extension conservationist interpreted the pictures as shown. The program ended with short remarks by other officers of the association and by representatives of the extension service and the Soil Conservation Service. In some instances those honored were later feted by local civic clubs. The success of these meetings makes it certain that this project will be continued from year to year by the local associations.

Pasture-forage-livestock project.—This project has been discussed from the standpoint of cooperative group action. It lends itself also, however, to leadership development. Thirty to 40 farmers are given special recognition each year for outstanding accomplishment in farm management, with respect to pasture management, feed supplies, and livestock enterprise. By publicly recognizing their accomplishments, and by using their farms as community demonstrations, these men are encouraged to carry on and improve their practices.

Level schools.—Interest in contour farming has increased greatly since the organization of the Soil Conservation Service. Many farmers were asking the extension service for assistance in running contour lines. The number of requests was such that they could not be taken care of by county agricultural agents or state extension workers. The extension conservationist, in cooperation with the extension engineers and the Soil Conservation Service, accordingly planned a series of level schools to which selected young men ranging in age from 18 to 30 were invited. At these schools particular emphasis was given to the problems of contour farming and how to meet them. Fields were studied from the standpoint of contour operations and, after preliminary instruction, lines were run by the group. From two to five instruments were available, including one homemade level device made from a carpenter's level. Instructions were given for the construction of these. The young men were advised where low-priced instruments could be purchased and the suggestion was given that they might run contour lines for neighbors for a small fee and thus defray part of the purchase price. They were advised to place themselves at the service of their neighbors and thus make themselves useful members of their community. Publicity was given in the local

papers telling of these schools and giving the names of the men who had received instructions. Seventy counties were reached by these schools. Contour lines were run on many farms as the result of this training. The close working relationship between the extension service and the Soil Conservation Service was a vital factor in the success of this project.

Irrigation schools.—This project phase has been discussed in relation to the correlation of the activities of two or more specialists working in related fields. These schools, aside from imparting information, served also to impart the germ of leadership in the minds of the young men who took the training. Local news stories set them apart from their fellows. The training received equipped them to be of service to their neighbors either by actual field assistance or by discussion with individuals or groups.

SUMMARY

This discussion of extension methods is far from complete. Many other items might be included, such as county program planning, leader training or delegate schools, district meetings with county agricultural agents to discuss subject matter material, yearly subject matter handbooks prepared by each specialist to be used by county agricultural agents as handy references, coordination and cooperation with research, office organization, etc. The illustrations given suffice to show how the extension service may so adapt its programs and its projects that they will lend themselves to leadership development, group action, integration of work of all agencies dealing with agricultural problems, and coordination of the efforts of specialists within the extension service. Without these aids the efforts of an individual extension worker cannot be most fruitful.

NOTES

CEREAL NURSERY SEEDERS[1]

THE nursery seeders described herein were designed for seeding rice nursery experiments at the Texas Agricultural Substation No. 4, Beaumont, Tex.

ADJUSTABLE SEEDER

It is desirable to have a readily adjustable nursery seeder in order that all varieties within a given experiment may be sown at approximately the same rate owing to the wide variation in weight per bushel of different varieties of rice. This was accomplished by mounting a small fluted feed, from an ordinary grain drill, upon a specially constructed angle iron frame as shown in Fig. 1.

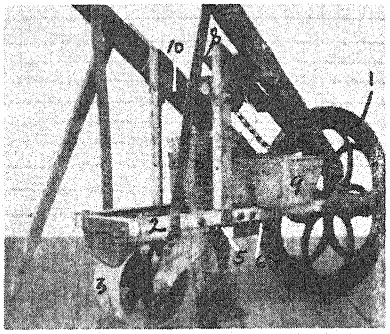

FIG. 1.—Adjustable seeder. (1) Drive wheel, 17 inches in diameter; (2) frame 25 inches long made of 1-inch angle iron; (3) Planet Junior press wheels, 7 inches in diameter; (4) Planet Junior K312 furrow opener; (5) ⅝-inch rectangular bar welded to furrow opener; (6) harrow bar 7½ inches long; furrow opener is attached to bar with harrow tooth clamp; (7) sheet metal grain spout; (8) fluted feed, from Hoosier one-horse grain drill made from 1897 to 1911; (9) sheet metal pan for retaining excess grain; (10) removable pin to allow operator to tip fluted feed forward for emptying excess seed which falls into pan.

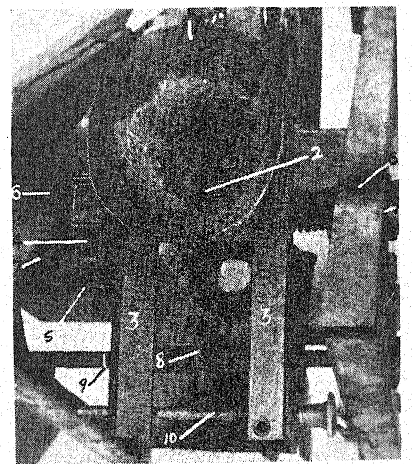

FIG. 2.—Fluted feed showing method of adjusting and cleaning. (1) Feed cup made of heavy gauge sheet metal; (2) feed roll; (3) ¾-inch angle iron attached to sides of fluted feed assembly with small stove bolts; (4) 11-tooth sprocket; (5) No. 25 drive chain (6-tooth sprocket on drive wheel); (6) oil holes for bearings (7); (8) knob for adjusting rate of seeding; (9) slot marker on adjusting rod; (10) removable pin to enable operator to tilt fluted feed forward for cleaning.

The weight per bushel of the rough rice was found to be one of the most important factors governing the rate at which the seed flowed

[1]Joint contribution of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Texas Agricultural Substation No. 4, Beaumont, Tex.

through the fluted feed. A chart based on a large number of trials was computed to show the settings necessary to sow approximately uniform weights of seed per row for varieties varying in test weight from 35 to 52 pounds. As shown in Fig. 2, the fluted feed is adjusted by

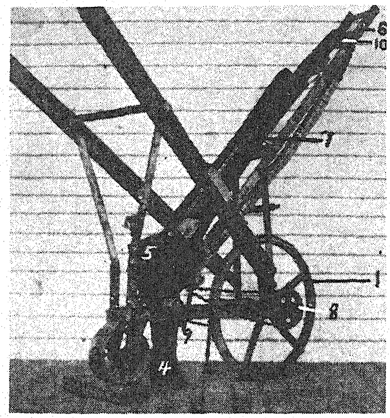

FIG. 3.—Nursery space seeder. (1) Drive wheel, 17 inches in diameter; (2) frame, strap iron 21 inches long; (3) press wheel; (4) Planet Junior K312 furrow opener; (5) sheet metal grain spout; (6) frame, strap iron 50 inches long; (7) sheet metal trough which is arched slightly in center to keep from bouncing when seeding on rough land; (8) 15-tooth drive sprocket; (9) 7-tooth sprocket; (10) 6-tooth sprocket on upper pin to carry chain.

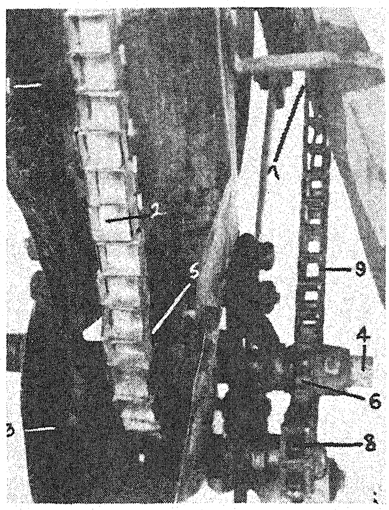

FIG. 4.—Close-up showing seeding mechanism of nursery space seeder. (1) Sheet metal trough; (2) seed cup; (3) sheet metal grain spout; (4) drive shaft, galvanized pipe, ⅞ inch in diameter; (5) 6-tooth sprocket; (6) 7-tooth sprocket; (7) 15-tooth drive sprocket; (8) 6-tooth sprocket for tightening drive chain; (9) No. 25 drive chain.

turning a knob attached to a ⅜-inch standard thread bolt. A total of 7¼ revolutions of the knob will correct for a difference of 17 pounds in test weight, or from 35 to 52 pounds per bushel, when seeding at the rate of 90 pounds per acre in rows spaced 1 foot apart. Marks on the rod, shown in Fig. 2, spaced for every two turns allow the setting to be made quickly and accurately.

FIG. 5.—Sheet metal cup attached to link of drive chain.

The furrow opener is a K312 Planet Junior plow attached by means of a short piece of harrow bar bolted to the frame of the seeder, as shown in Fig. 1. A rectangular bar the size of a harrow tooth was welded to the upper portion of the furrow opener. A harrow tooth clamp attached to the furrow opener holds it in place. The opener can be readily adjusted for seeding at different depths. A sheet metal grain spout is attached on the back of the furrow opener.

A seeder of this type has been used in sowing nursery experiments at Beaumont for 4 years. Uniform stands have been obtained each year, whereas in previous years, when sown by hand, the stands were rather variable.

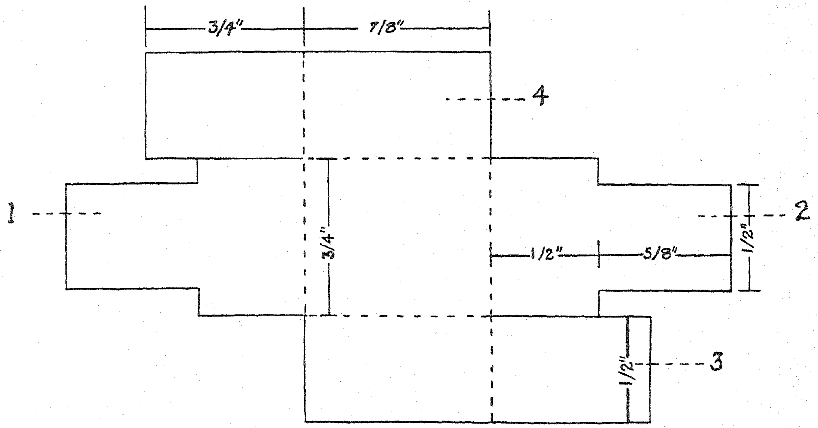

FIG. 6.—Diagram showing how cups were made. (1, 2) Bent down and fastened to chain link; (3, 4) bent up to form sides of cup.

FIG. 7.—Rows sown with space seeder.

Each lot of seed was placed in a section of an automobile inner tube before sowing and rubbed thoroughly to remove all stems and beards. After rubbing, the dust, stems, and light-weight grains were removed with a laboratory aspirator. This operation materially reduced the variation in bushel weight among different varieties and enabled the grain to flow through the fluted feed at a more uniform rate. A piece of inner tube at least 5 inches in diameter and 2 feet in length was found to be the most satisfactory for cleaning samples that varied from 1 to 2 pounds in weight.

SPACE SEEDER

The space seeder, shown in Fig. 3, consists of small sheet metal cups ⅞ inch by ¾ inch and ½ inch deep attached to each link of a No. 25

cast drive chain, as shown in Fig. 4. The cup shown in Fig. 5 was made from 28 gauge sheet metal cut according to the diagram shown in Fig. 6. The speed of the chain to which the cups are attached is so regulated that a seed placed in each cup is dropped every 4 inches. A single seed is dropped in each cup by hand, and any extra seeds dropped accidentally in a cup are removed with forceps. The furrow opener used on this seeder is similar to the one on the adjustable seeder and was attached in the same manner.

Two men, one filling the cups and the other pushing the seeder, can sow approximately 450 rod rows in a 9-hour day. With two men filling the cups and a third pushing the seeder, as many as 560 rows were seeded in 9 hours. Plants in rows sown with this seeder are shown in Fig. 7. This type of seeder has been used during 1937 and 1938 and the spacings have been satisfactory. The stands have been superior to those obtained from hand seeding in previous years.—H. M. BEACHELL, *Texas Agricultural Substation No. 4, Beaumont, Texas.*

PORTABLE FIELD DRIER[1]

IN recent studies on the root reserves of the European bindweed (*Convolvulus arvensis* L.), it was necessary to have a drier or dehydrator which could be used in the field. Four units have been

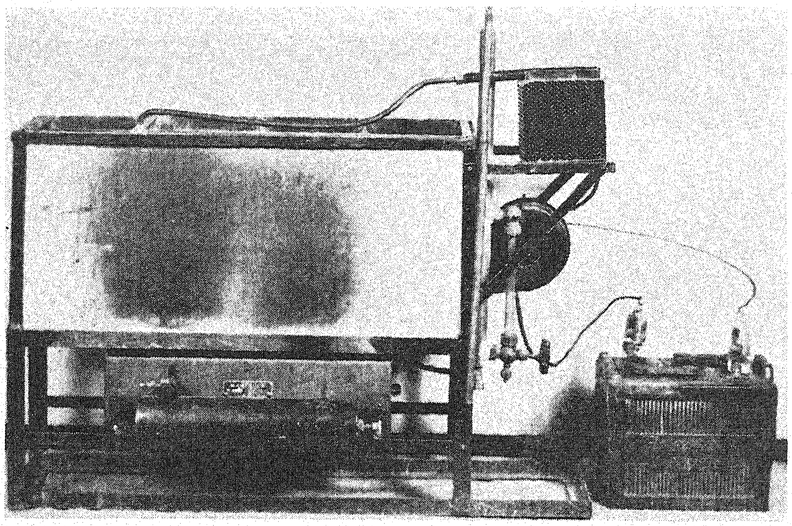

FIG. 1.—Portable field dehydrator.

assembled and one has been used for the past three seasons. The external appearance of the equipment is shown in Fig. 1, and the internal construction is illustrated in Fig. 2.

[1]Journal Paper No. J-618 of the Iowa Agricultural Experiment Station, Project 484, in cooperation with the U. S. Dept. of Agriculture.

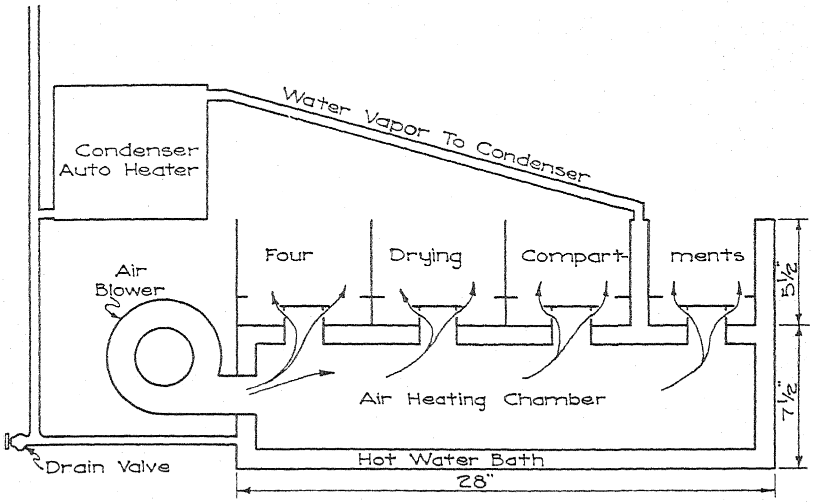

FIG. 2.—Diagrammatic view of the construction of portable field drier.

The external dimensions of the drier in its supporting angle iron frame are $36 \times 9\frac{1}{2} \times 23$ inches. The dimensions of the enclosed structure are indicated in Fig. 2. Air from a 6-volt blower enters a compartment heated by a water jacket. Baffles inside of the heating compartment are desirable to prevent air channels. The hot air from the heating compartment is vented into four drying chambers through adjustable vents. The drying compartments are provided with removable screen bottoms and should have at least an inch baffle around the edges to force the air through the center of the sample placed in the compartment. The end compartment is water-jacketed to keep the temperature as high as possible. A steam outlet from this jacket leads to a condenser made from an auto heater. The condensate returns to the water bath through a copper pipe of rather large diameter to facilitate filling and also to serve as blow-off if the bath is overheated. A rubber tube can be placed over the end of this vent and led to the ground to prevent wetting of the samples by escaping water.

The water bath is heated with a portable gasoline camping stove. Some form of shelter or tent is desirable to prevent the wind from blowing out the flame of the stove. An asbestos covering around the sides of the tank is desirable to prevent excess radiation. This assembly on an angle iron frame is shown in Fig. 1.

After the drier is in operation and the stove adjusted, the temperatures in the four compartments will be about 80°, 75°, 70°, and 65°, respectively, and will stay practically constant. The sample to be dried (about 200 grams) is placed on a piece of cheesecloth 24 inches square and moved progressively from the hotter drying chamber to the cooler chamber as it dries. If one wishes to stop enzyme action before drying the tissue, the sample may be given a preliminary heating in a separate unit at the temperature of boiling water before being placed in the drier. Root samples having about 80% moisture, such as those used in these studies, will be completely dry in 3 hours.

A standard 6-volt battery will operate the blower for about 90 hours. Continuous service can be maintained with two batteries which are alternately used and charged. In hot, still weather one radiator may not offer sufficient condensing surface to prevent loss of water vapor. In such a case, a second radiator can be mounted in tandem with the first.—R. M. HIXON AND A. L. BAKKE, *Iowa State College, Ames, Iowa.*

A TOOL FOR THE RAPID SAMPLING OF SOILS

MEN interested in soils frequently have occasion to take composite samples of soils. Doing this with a soil auger or spade is at best a rather slow job, especially when a number of samples are taken.

In Fig. 1 are shown tools that have proved very satisfactory for rapidly taking a number of composite soil samples from cultivated land. They consist of a tube for sampling through the A-horizon and a tool for removing the sample. The sampling tool was made from an 18-inch piece of plumber's brass tubing with a handle shaped from a piece of wood fitted into one end. A slot for facilitating the removal of the soil was cut into one side of the tube with a thin emery wheel and a hack saw blade. The bottom end of the tube can be kept sharpened with a large-size cork borer sharpener or mill file.

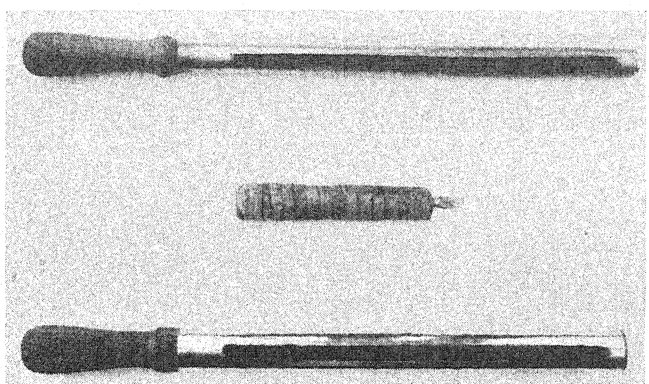

FIG. 1.

Since the brass tubing is made in a number of diameters, a size of tube that will provide the desired quantity of sample from a given number of borings can be chosen. An ordinary screw driver can be used for removing the sample. Shown in Fig. 1 is one on which the handle was extended almost the full length of the shank to make it less tiresome to use.

Using the small tube and screw driver shown in Fig. 1, one operator can readily take as many as 50 composite samples consisting of 20 borings each in a day.—FRANKLIN L. DAVIS, *Louisiana Agricultural Experiment Station, University, La.*

A METHOD FOR OBTAINING A CONTINUOUS MEASUREMENT OF SOIL MOISTURE UNDER FIELD CONDITIONS

A METHOD has been devised for making *in situ* under field conditions a continuous measurement of soil moisture. It consists of imbedding in the soil a standardized block of $CaSO_4$ (plaster of paris). The moisture content of this material varies directly with that of the soil. Since the dielectric constant of plaster of paris is proportional to its moisture content, a measure of the conductivity of the block is a measure of soil moisture. Conductivity determinations are easily made by means of electrodes and a form of the Wheatstone bridge.

This device measures soil moisture ranging from the wilting point to the field capacity or it is really a measure of the available water. It denotes the wilting point accurately. By knowing the wilting point and the available water, the total water content is thereby also known. The method possesses a surprisingly high degree of accuracy. —G. J. BOUYOUCOS AND A. H. MICK, *Michigan Agricultural Experiment Station, East Lansing, Mich.*

AGRONOMIC AFFAIRS

SOME ACTIVITIES OF THE DIVISION OF BIOLOGY AND AGRICULTURE OF THE NATIONAL RESEARCH COUNCIL

THE following brief summary of certain activities of the Division of Biology and Agriculture, National Research Council, is based upon the 1937–1938 annual report of the Chairman, Dr. R. E. Coker, and from supplemental information obtained from him relative to development since July 1, 1938:

INTERDIVISIONAL COMMITTEE ON AEROBIOLOGY

Dr. E. C. Stakman has been named chairman, to succeed the late Dr. Fred C. Meier who, with Dr. E. B. McKinley and others, was lost with the ill-fated Hawaiian Clipper, while on an official flight in the interest of aerobiology. The Carnegie Corporation of New York has made available for future use of the Committee the balance of some $2,400 remaining from the Meier grant.

COMMITTEE ON ECOLOGY OF GRASSLANDS IN NORTH AMERICA

This committee, of which Dr. V. E. Shelford is chairman, is sponsoring a movement to set aside more or less extensive grassland areas and preserve them for research and as controls against ordinary methods of utilization in connection with agricultural and other developments of civilization. Reports growing out of the work of the committee emphasize the necessity for reserving grassland areas comparable in extent and purpose to existing reservations of forest areas in national parks. These reports also list and discuss the kinds of studies of plants and animals, of their interrelations and of their relationships to soils, climate, etc., which might be made possible and be promoted by the reservation of appropriate areas. Two papers have appeared in recent issues of the SCIENTIFIC MONTHLY, *viz.*, "The Need for Research on Grasslands," by Herbert C. Hanson and C. T. Vorhies, March 1938; and "Check-Areas as Controls in Land Use," by Herbert C. Hanson, February 1939.

COMMITTEE ON FORESTRY

The Committee on Forestry, of which Dr. Raphael Zon is chairman, has just completed the manuscript of what seems to be a monumental bibliography of forestry in North America up to 1930. The committee has also completed a report on "Forest Research in the United States."

THE NAPLES ZOOLOGICAL STATION

The National Research Council Table in the Naples Zoological Station is available to one or more qualified Americans who may be interested in availing themselves of the facilities of that station during the ensuing year. A notice regarding the table was published in SCIENCE for May 20, 1938. Application should be directed to the office of the Division of Biology and Agriculture, National Research Council, Washington, D. C.—P. V. CARDON, *representing the American Society of Agronomy and the National Research Council.*

THE NEW AUTHOR AND SUBJECT INDEX

THE cumulative author and subject Index to Volumes 21 to 30, inclusive, 1929–1938, of the JOURNAL is now ready for distribution. It makes 83 pages and is paper covered. The new Index is nearly double the size of the Index to the first twenty volumes of the JOURNAL, published in 1929, a few copies of which are still available.

The new Index will be sold at $1.00 per copy to cover the cost of publication and handling charges.

NEWS ITEMS

DOCTOR EDMUND C. SHOREY died in Washington, D. C., on January 30, following a long illness. Dr. Shorey was a native of Canada and received his training at Queens University, Kingston, Ontario. At the time of his retirement in 1935 and for many years prior to that date he was associated with the Division of Soil Fertility Investigations of the U. S. Dept. of Agriculture.

THE CANADIAN SEED GROWERS' ASSOCIATION will hold its 1939 meeting in Victoria, British Columbia, June 14 to 16. The President of the Association is F. W. Townley-Smith of Lashburn, Sask., and the Secretary-Treasurer, W. T. G. Wiener of Ottawa, Ontario.

ERRATUM

CORRECTIONS are called for in two of the formulae appearing in the article on "The Analysis of Variance with Special Reference to Data Expressed as Percentages", by Andrew Clark and Warren H. Leonard on pages 55 to 66, inclusive, of the January 1939 number of this JOURNAL. The second formula on page 58 should read

$$t = \log \frac{p}{1-p}.$$

On page 59, the expression in the third paragraph should be written as follows: $\frac{S(n_r-1)\ (V_r-V)^2}{2V^2}$.

JOURNAL
OF THE
American Society of Agronomy

VOL. 31 APRIL, 1939 NO. 4

GENETICS OF BARLEY[1]

D. W. ROBERTSON[2]

OF the cereal crops, barley offers a superior opportunity for genetic studies. It is adapted to a wide variety of conditions and shows many different characters. Since all of the cultivated barleys have seven chromosome pairs, they afford an excellent opportunity to study the various character pairs with respect to their linkage groups.

A rather extensive review of the literature on barley genetics was published in mimeographed form by Robertson and Wiebe (17).[3]

In studying the interaction of the various factor pairs, a more difficult problem is found than in the case of cross fertilized crops. Hand pollination of each floret becomes a rather tedious job in order to obtain enough plants to make the backcross data reliable. In most of the studies F_2 data verified in F_3 were used. A few linkages are reported where backcrosses to the F_1 were made. It is not always possible to obtain on the first trial the characters in the proper combinations; however, synthetic parents are being built up as rapidly as possible.

The material reported in this paper will deal with the linkage of characters in the common cultivated barleys, *Hordeum vulgare*, *H. intermedium*, *H. distichum*, and *H. deficiens*, all of which have been reported to have seven haploid chromosomes. A short description of some of the newer characters is given at the end of the paper. It is unfortunate that a complete check of all the known characters is not available. However, a collection of these characters is being made by G. A. Wiebe of the U. S. Dept. of Agriculture, and also by the Colorado Experiment Station. Where possible, all identical characters are being checked and many of those reported by Robertson and Wiebe (17) are available to workers in the field.

To date seven linkage groups, in which two or more characters have been located, have been reported in barley.

GROUP I

Group I contains the two-row versus six-row factor pair (Vv). In

[1]Contribution from the Department of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo. Also presented at the annual meeting of the Society, November 16, 1938, in Washington, D. C. Received for publication December 9, 1938.

[2]Associate agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 282.

this group the following factor pairs have been located. Toothed versus untoothed lemma was reported by Ubisch, cited by Wexelsen (22), with 16.6% crossing over and by Wexelsen (22) with 15.4% crossing over with (Vv). This character is designated by the letters (Gg) (Robertson and Wiebe).[4] Awned versus awnless (Lk lk) is reported by Kuckuck (9) to be linked with (Vv), the row factor pair, with 9.57% crossing over. Robertson (16) found the factor pair (Pr pr) for purple versus non-purple straw to be linked with (Vv) with 9.0% crossing over.

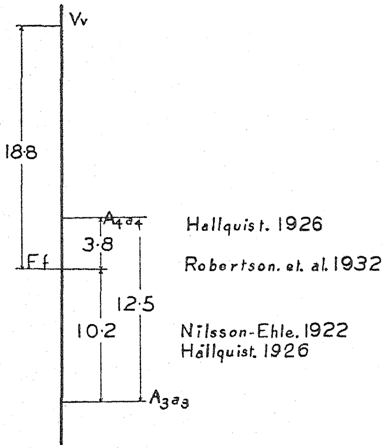

FIG. 1.

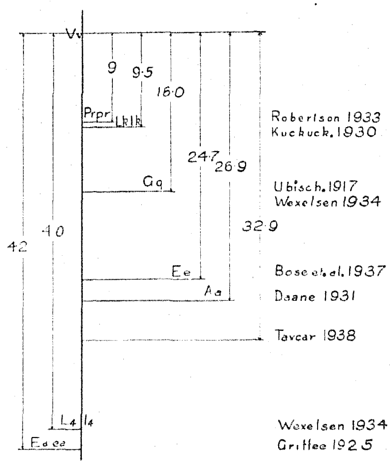

FIG. 2.

Bose, *et al.* (1) have found that a factor pair (Ee) for awns versus no awns on the outer glumes is linked with (Vv), two-row versus six-row, with 24.7% crossing over. The factor pair (Ff) for green versus chlorina seedlings in Minn. 84–7 is located in group I with 18.3% crossing over. Two white seedling factor pairs (A_3a_3) and (A_4a_4) described by Hallquist (5) and Nilsson-Ehle (13) are located close to the (Ff) factor pair. Their relationship to the (Vv) factor pair, however, has not been determined. Daane (3) found a green versus white seedling factor pair (Aa) linked with the (Vv) factor pair with 26.9% crossing over. An internode length factor pair (L_4l_4) is reported by Wexelsen (22) to be linked with the (Vv) factor pair with 40.0% crossing over. (See Figs. 1 and 2.)

Buckley (2) studied several color factors affecting the lemma. Fig. 3 presents the location of the following factors on the chromosome map: (P_cp_c) purple versus white veined lemma, (Re re) red versus white pericarp, and (Pp) purple versus white lemma. Tavcar (20) studied the inheritance of a factor pair (Rin rin) for number of rachis internodes and found a linkage between two-row versus six-row and high and low internode number. He calculated graphically a crossover value of 32.94%.

[4]Throughout this paper the symbols suggested by Robertson and Wiebe (17) will be used.

Several other factor pairs are reported as being located in group I, but so far no crossover values have been determined. A factor pair for early versus late heading is located in this group by Griffee (4) and Neatby (12).

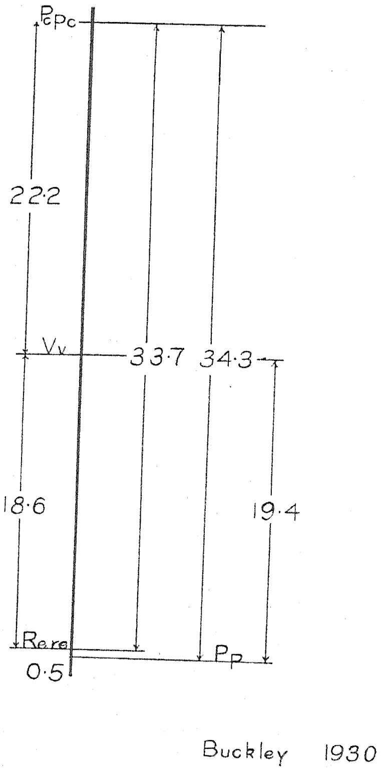

FIG. 3.

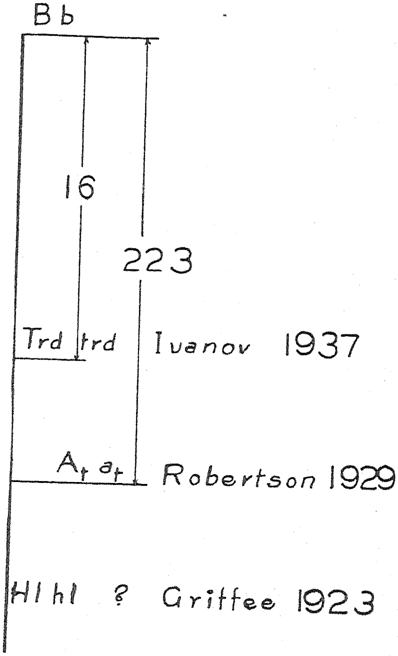

FIG. 4.

GROUP II

Black versus white lemma and pericarp (Bb) is located in group II (Fig. 4). Several other factor pairs are also located in this group. A factor pair (A_ta_t) for green versus white seedlings has a crossover value of 22.29%, with the (Bb) factor pair for black versus white lemma and pericarp. Ivanova (8) reports the linkage of a factor pair (Trd trd) for an extra outer glume and the (Bb) factor pair with 15.3 to 16.9% crossing over. The third outer glume behaves as a simple recessive to normal glumes. Griffee (4) found one of the factor pairs (Hl hl) for resistance versus suscep-

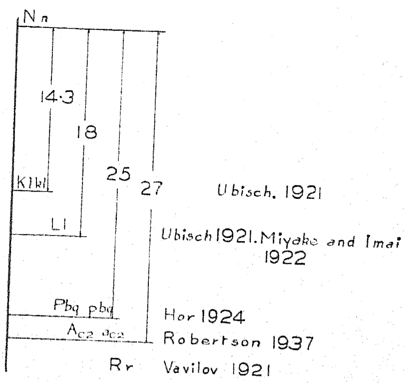

FIG. 5.

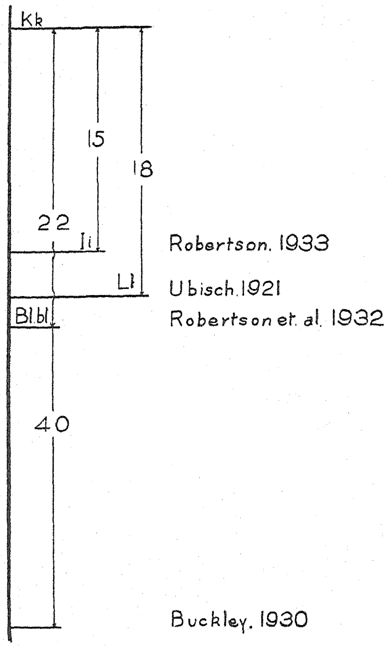

FIG. 6.

tibility to *H. sativum* in this group.

GROUP III

Group III (Fig. 5) contains the factor pair (Nn) for covered versus naked caryopsis. Several factor pairs have been found by various workers in this linkage group. Hooded versus long awned (Kl kl) was found to be linked with covered versus naked with 14.3% crossing over by Ubisch, cited by Daane (3). A factor pair for dense versus lax heads (Ll) was found to be located in this group by Ubisch, cited by Wexelsen (22), and by Miyake and Imai (11) with from 13.0 to 23.0% crossing over with (Nn).

Two different factors for dense versus lax may be present, but further work is necessary before the point can be definitely determined. Hor (6) found general versus restricted pubescense of the outer glumes (Pbg pbg) to be linked with covered versus naked with 23.0 to 27.0% crossing over. A white seedling factor pair ($A_{c2}a_{c2}$) found in Coast II has a crossover value of 27.24±2.04% with covered versus naked (Nn). Vavilov (21) reports a linkage between a factor pair for rough versus smooth awn and the (Nn) factor pair.

GROUP IV

The factor pair (Kk) for hoods versus awns is located in group IV (Fig. 6). Another factor pair for dense versus lax has been placed in this group by Ubisch with from 16.0 to 20.0% crossing over. One of the factor pairs for blue versus white aleurone color has been located in this group by Buckley (2) with 40.6% crossing over and by Robertson, *et al.* (15) with 22.0% crossing over. The factor pair (Ii) for intermedium versus non-intermedium is linked with hoods versus awns with 15.12% crossing over. Wexelsen (22) cited Ubisch who found a factor pair (Ll) for rachis internode length in this group.

GROUP V

Group V (Fig. 7) contains the main factor pair (Rr) for rough versus smooth awns. The long versus short-haired rachilla factor pair (Ss) has been found in this group with from 28.05 to 45.5% crossing over with (Rr). The following workers have found different crossover values: Daane (3), 28.05%; Sigfusson (18), 30.8%; Wexel-

sen (22) 30.0%; Robertson, *et al.* (15), 34.63%; Hor (6), 35.0%; and McGregor (10), 42.7 to 45.5%. A correlation between the factor pairs for branched versus unbranched stigma (Uu) and rough versus smooth awns was found, indicating that some of the factor pairs for

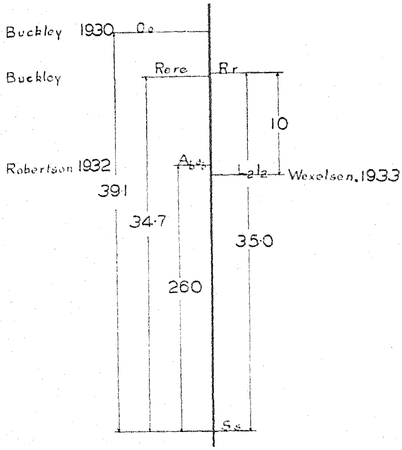

FIG. 7.

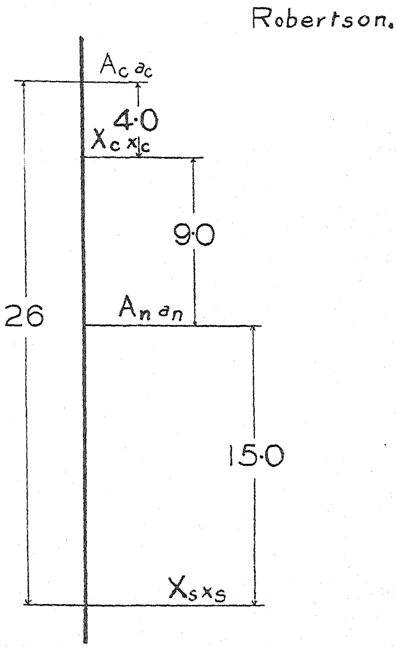

FIG. 8.

stigma branching are located in this group. Griffee found a correlation between resistance versus susceptibility to *H. sativum* and the rough versus smooth awn factor pair. Wexelsen found a linkage between the factor pair (L_2l_2) for long versus short internode and rough versus smooth awn with 10.0% crossing over. Buckley (2) found a linkage of the factor pair (Ss) and a factor pair (Re re) for red versus white pericarp with 34.7% crossing over. The factor pair (Oo) for white versus orange lemma was also found to be linked with the factor pair (Ss) with 39.1% crossing over. A white seedling factor pair (A_ba_b) found in Black Hulless barley was linked with the factor pair (Ss) with 26% crossing over.

GROUP VI

Group VI (Fig. 8) contains several factor pairs for seedling lethals. No mature plant character has yet been found to be linked in this group. The following factor pairs are located in this group: (A_ca_c) for green versus white seedlings in Colsess I, (X_cx_c) for green versus xantha seedlings in Colsess IV, (A_na_n) for green versus white seedlings in Nigrinudum I, and (X_sx_s) for green versus yellow seedlings in Smyrna I.

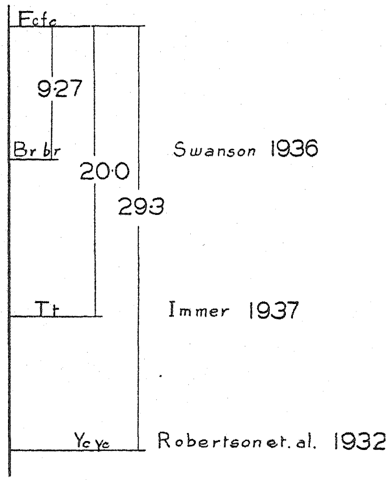

FIG. 9.

GROUP VII

This group (Fig. 9) contains the factor pair (F_cf_c) for green versus chlorina seedlings in Colsess V and the factor pair (Y_cy_c) for green versus virescent seedlings in Coast III. The normal versus brachytic factor pair (Br br) reported by Powers (14) was found by Swanson (19) to be linked with the green versus chlorina factor pair with 9.27% crossing over. A factor pair (Tt) for resistance versus susceptibility to *P. graminis tritici* (Peatland) is reported by Immer (7) to be linked with the green versus chlorina factor pair with 20% crossing over.

DESCRIPTION OF CHARACTERS

A brief discussion of the various characters referred to in the above paper is given below to familiarize workers in barley genetics with them.

1. Six-row versus non-six-row (Vv). Fig. 10. A: (a) six-row, (b) two-row.
2. Toothed versus untoothed veins on the lemma (Gg). Fig. 10. B: (a) toothed, (b) untoothed.
3. Awned versus awnless (Lk lk). Fig. 10. C: (a) awnless, (b) awned.
4. Awns versus no awns on the outer glumes (Ee). Fig. 10. D: (a) awned outer glumes, (b) awnless outer glumes.
5. Green versus chlorina seedlings in Minn. 84–7 (Ff). The seedlings are "cosse green" (Ridgeway Plate V). The plants grow to maturity but are somewhat stunted.
6. Purple versus white veined lemma (P_cp_c). The veins on the lemma are purple in color. This character may fade out at maturity.
7. Red versus white pericarp (Re re). The pericarp color is reddish brown. This character varies considerably and may not be clear cut under all environments.
8. Purple versus white lemma (Pp). The lemma is purple in color.
9. Black versus white lemma and pericarp (Bb). The lemma and palea are black.
10. Normal versus third outer glume (Trd trd). A third outer glume is present. Ivanova (8).
11. Covered versus naked caryopsis (Nn). Fig. 11. E: (a) covered caryopsis, (b) naked caryopsis.
12. Pubescent versus restricted pubescence on outer glume (Pbg pbg). Fig. 11. F: (a) restricted pubescence, (b) pubescent outer glume.
13. Hoods versus awns (Kk). Fig. 11. G: (a) hooded, (b) awned.
14. Blue versus non-blue aleurone (Bl bl). The aleurone color in the absence of red or black pericarp color is blue. Typical non-blue aleurone is found in the

variety Nepal C. I. 595, blue aleurone in Faust C. I. 4579. This character shows xenia.

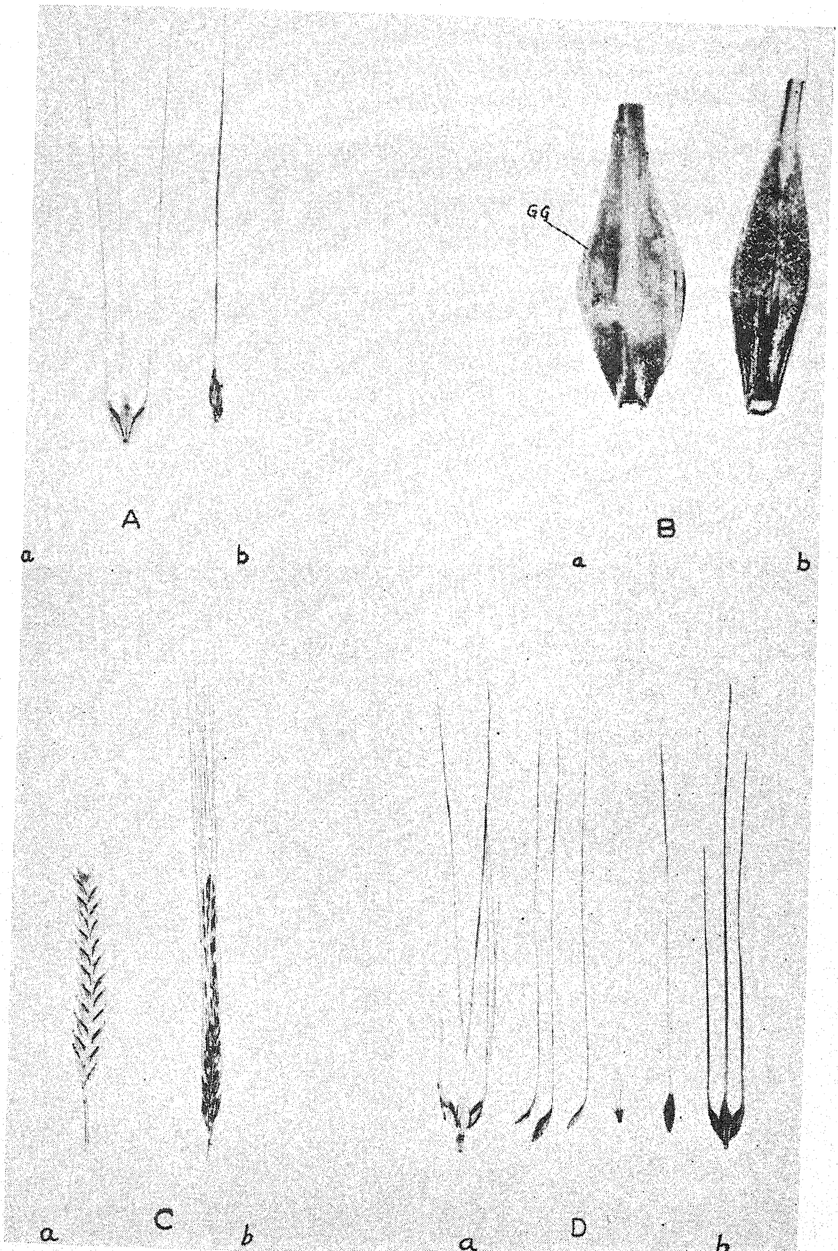

FIG. 10.

15. Intermedium versus non-intermedium (Ii). Fig. 11. H: (a) intermedium (H. dis. nigrinudum), (b) non-intermedium (H. def. nudideficiens), (c) a very extreme type of deficiens.
16. Rough versus smooth awn (Rr). Fig. 12. I: (a) smooth awn, (b) rough awn.
17. Long versus short-haired rachilla. Fig. 12. J: (a) long-haired rachilla, (b) short-haired rachilla.

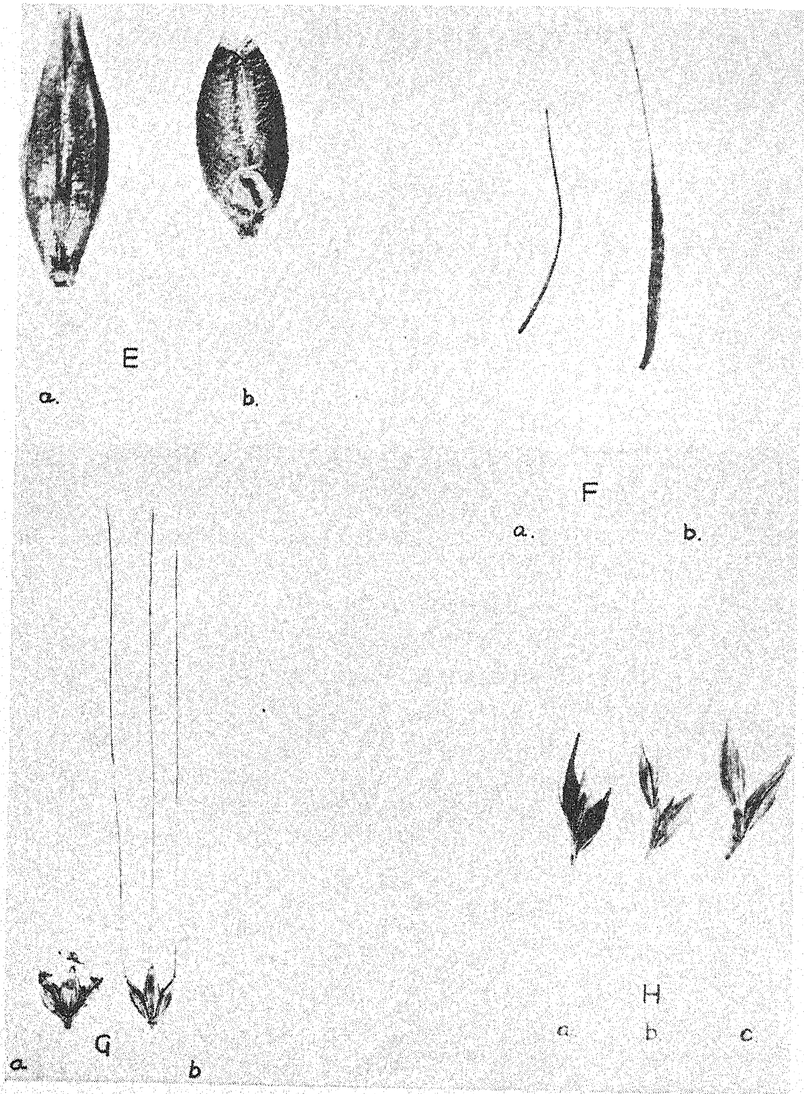

FIG. 11.

18. Branched versus unbranched stigma (Uu). Three factor difference. Fig. 12. K: (a) branched, (b) unbranched.
19. Long versus short internode. Fig. 12. L: (a) Abed Binder (l_3l_3, L_4L_4, L_5L_5), (b) Machine (L_3L_3), (c) Asplund (l_4l_4, l_5l_5).

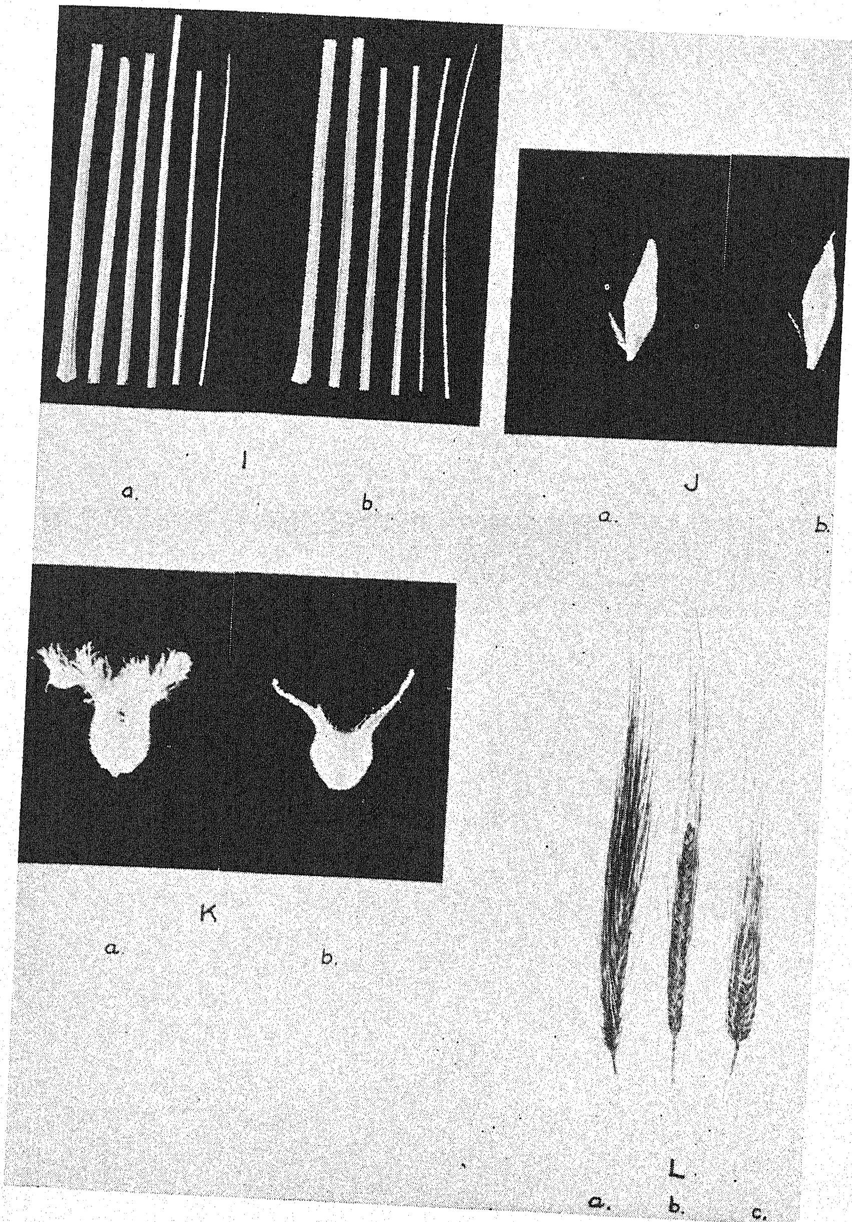

FIG. 12.

20. Green versus white seedlings in Colsess I. The white seedlings die in the seedling stage. The other white seedlings discussed in this paper are similar in appearance to the Colsess I seedling, and die in the seedling stage. They are recessive to normal green.
21. Green versus xantha seedlings in Colsess IV (X_cx_c). The xantha seedlings die in the seedling stage. At high temperatures these seedlings will mature seed. They are "bright chalcedony yellow" (Ridgeway Plate XVII).
22. Green versus yellow seedlings in Smyrna I (X_sx_s). The yellow seedlings die in the seedling stage. They are "citron green". (Ridgeway Plate XXXI).
23. Green versus chlorina seedlings in Colsess V (F_cf_c). The seedlings are "dull green yellow" (Ridgeway Plate XVII). The seedlings grow to maturity.
24. Green versus virescent seedlings in Coast III (Y_cy_c). The first two leaves of the virescent seedlings have green tips. They survive under field conditions at Fort Collins for four or five weeks. The amount of green on the tip of the leaves varies.
25. Normal versus brachytic (Br br). The brachytic plant has shorter nodes than normal plants.
26. Normal versus orange lemma. The lemma is orange colored. The rachis is colored deep orange. This character may be the same as red rachis C. I. 5649.

LITERATURE CITED

1. Bose, R. D., Aziz, M. A., and Bhatnayar, M. P. Studies in Indian barleys. IV. The inheritance of some anatomical characters responsible for lodging and of some ear-head characters in an interspecific cross between two Pusa barleys. Ind. Jour. Agr. Sci., 7:4–88. 1937.
2. Buckley, G. F. N. Inheritance in barley with special reference to the color of caryopsis and lemma. Sci Agr., 10:460–492. 1930.
3. Daane, A. Linkage relations in barley. Minnesota Agr. Exp. Sta. Tech. Bul. 78. 1931.
4. Griffee, F. Correlated inheritance of botanical characters in barley and manner of reaction to *Helminthosporium sativum*. Jour. Agr. Res., 30:915–935. 1925.
5. Hallquist, C. Koppelungen und Synthetische Lethalitat bei den Chlorophyllfactoren der Gerste. Hereditas, 8:229–254. 1926.
6. Hor, K. S. Interrelations of genetic factors in barley. Genetics, 9:151–180. 1924.
7. Immer, F. R. Rust resistance in Peatland. Correspondence. 1937.
8. Ivanova, K. V. A new character in barley, "third outer glume," its inheritance and linkage with color of the flowering glumes. Bul. Appl. Bot., Gen. and Plant Breed., Ser. II, Gen., Plant Breed. and Cytol., 7:339–353. 1937.
9. Kuckuck, von H. Versuch Einer Vorläufigen Chromosomentopographie bei Gerste. Der Züchter Hept., 3:68–72. 1930.
10. McGregor, W. G. Inheritance studies in barley. Master's thesis, University of Minnesota. 1929.
11. Miyake, K., and Imai, Y. Genetic studies in barley, I. Bot. Mag., 36:25–38. 1922. (In Japanese. Translation obtained from Dr. G. A. Wiebe.)
12. Neatby, K. W. An analysis of the inheritance of quantitative characters and linkage in barley. Sci. Agr., 9:701–718. 1929.
13. Nilsson-Ehle, H. Uber Freie Kombination und Koppelung Verscheidener Chlorophyll-Erbeinheiten bei Gerste. Hereditas, 3:191–199. 1922.
14. Powers, LeRoy. The nature of the interaction of genes affecting four quantitative characters in a cross between *Hordeum deficiens* and *vulgare*. Genetics, 21:398–420, 1936.
15. Robertson, D. W., Deming, G. W., and Koonce, D. Inheritance in barley. Jour. Agr. Res., 44:445–466. 1932.
16. ————. Inheritance in barley. Genetics, 18:148–158. 1933.
17. ————, and Wiebe, G. A. Genetic factors in barley. Mimeographed. 1938.

18. SIGFUSSON, S. J. Correlated inheritance of glume color, barbing of awns, and length of rachilla hairs in barley. Sci. Agr., 9:662–674. 1929.
19. SWANSON, S. P. Genetic and cytological studies on a brachytic mutation in barley. Thesis submitted for the Ph.D. degree, University of Minnesota. 1936.
20. TAVCAR, A. Vererbunghsart der Spindelstufenzahl bei Bastardierungen einiger *distichum* x *vulgare* Wintengersten. Zeit. für induktive Abstammungsvererbungslehre, 75:106–123. 1938.
21. VAVILOV, N. I. De L'origine d'orge a barbes lisses. Bul. App. Bot. and Plant Breed., 12:105–127. 1921.
22. WEXELSEN, H. Quantitative inheritance and linkage in barley. Hereditas, 18:307–348. 1934.

LIMESTONE MOBILIZES PHOSPHATES INTO KOREAN LESPEDEZA[1]

WM. A. ALBRECHT and A. W. KLEMME[2]

KOREAN lespedeza has found wide acceptance as a forage crop to replace clovers and similar crops which have been recognized as sensitive to the soil's low supply of calcium. Since this newer legume is a nitrogen fixer, we may be inclined to ascribe to it the protein content commonly accepted for clover hays. This is apt to be done irrespective of the soil conditions under which the crop is grown. Since the lime level of the soil is a significant factor in determining nitrogen fixation by soybeans, for example, the question arises whether Korean lespedeza, on those soils too deficient in lime for success with clover, can produce as high a protein concentration in the forage as when given limestone or phosphates. In an attempt to supply the answer to this question, attention was given to the composition of the lespedeza harvest on the experimental plats of the Department of Field Crops of the Missouri Agricultural Experiment Station, given these soil treatments.

Samples of the lespedeza hay were gathered on August 7, 1938, from 12 plats as quadruplicates of the three treatments, namely, (a) no treatment, (b) superphosphate, and (c) limestone and superphosphate. The samples were separated into the grass and lespedeza portions and relative percentages of each determined. Weights of the hay crop were taken and the samples of lespedeza as separated analyzed for their contents in nitrogen, calcium and phosphorus with the results given in Table 1. The roots were also harvested in specified areas and similarly handled. No analyses were made of the grass. In the calculations, the grass portion was assigned the nitrogen content of 1.2%, and taken to have the same phosphorus and calcium contents as those in the lespedeza fraction of the hay.

Perhaps the first significant item in the data is the much larger yield increase of hay by the combined treatments of limestone and superphosphate than by the superphosphate alone. In the former treatment this effect amounted to an increase of 82.9%, and in the latter only 16.6%. No limestone additions were made as a single treatment which would serve to separate the effects.

Such a response in the form of increased crop weight is decidedly significant in pointing out that even though lespedeza may do fairly well on Putnam silt loam without soil treatment, it does better to the extent of over 80% when this soil is given the treatments of limestone and phosphorus, both recognized as essential on this soil type if it is to grow sweet clover or other legume crops successfully.

More significant than the increased crop weight, however, are the changes in crop composition, especially in nitrogen, as a consequence of soil treatment with limestone. When only superphosphate was supplied, the nitrogen composition was increased insignificantly, or

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 594. Received for publication December 24, 1938.

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from 1.79 to 1.81%. When limestone supplemented the phosphate, the nitrogen content rose to 2.09%, or an increase in absolute of 0.30%, or comparatively, of more than 17%. When the increased yields and the higher concentrations of nitrogen are converted into protein harvest per acre, the superphosphate used alone increased this 31.5%, while the limestone and superphosphate together gave an increase of 146.3%. Some of the differences are more clearly shown in Fig. 1.

TABLE 1.—*Influence of limestone on mobilizing phosphates into Korean lespedeza and on forming protein in the plants.*

Soil treatment	Yield per acre, lbs.	Calcium			Phosphorus				Nitrogen		Protein, lbs. per acre
		%	Lbs. per ton	Lbs. per acre	%	Lbs. per ton	Lbs. per acre	Increase lbs. per acre	%	Lbs. per ton	
					Hay						
No treatment	762 (60%)*	0.935	18.7	7.12	0.189	3.78	1.44	—	1.79	35.8	85.2 (73.9)
Phosphate	800 (90%)	0.986	19.7	8.76	0.201	4.02	1.78	0.34	1.81	36.2	100.5 (97.2)
Limestone & phosphate	1394 (100%)	0.945	18.9	13.17	0.189	3.78	2.53	1.09	2.09	41.8	182
					Stubble and Roots						
No treatment	454	0.557	11.1	2.52	0.243	4.86	1.03	—	1.99	39.8	56.4
Phosphate	463	0.635	12.7	2.94	0.240	4.80	1.11	0.08	2.19	43.8	63.5
Limestone & phosphate	579	0.661	13.2	3.84	0.212	4.24	1.22	0.19	1.98	39.6	71.7

*Figures in parenthesis represent the percentage of lespedeza in the hay and the protein harvest per acre corrected for the grass admixture. Chemical analyses were made under the direction of Dr. L. D. Haigh, Department of Agricultural Chemistry.

In terms of the concentrations of phosphorus and calcium in the crop, each remained the same in the hay whether from the plats with no treatment or from those given limestone and superphosphate together. In the hay where superphosphate was used alone, both calcium and phosphorus moved into it to greater concentrations than in the other treatments. Since the yields were not increased extensively by this single treatment, this increased concentration may represent the influence of some limiting factor in holding down the yield through which the increased phosphate concentration may have resulted.

The increased total phosphorus in the larger crop where limestone was used as a supplement to phosphate indicates the beneficial effect by liming in mobilizing the phosphorus into the crop. The use of superphosphate only gave an increase in the total crop phosphorus of slightly more than ⅓ pound, or about 25%; but, when limestone was also introduced, this same phosphate application resulted in giving an increased phosphorus harvest in the crop of 1.09 pounds, or an increase of 75%. The corresponding increases in the total calcium taken by the crop amounted to 23% and 85%, respectively.

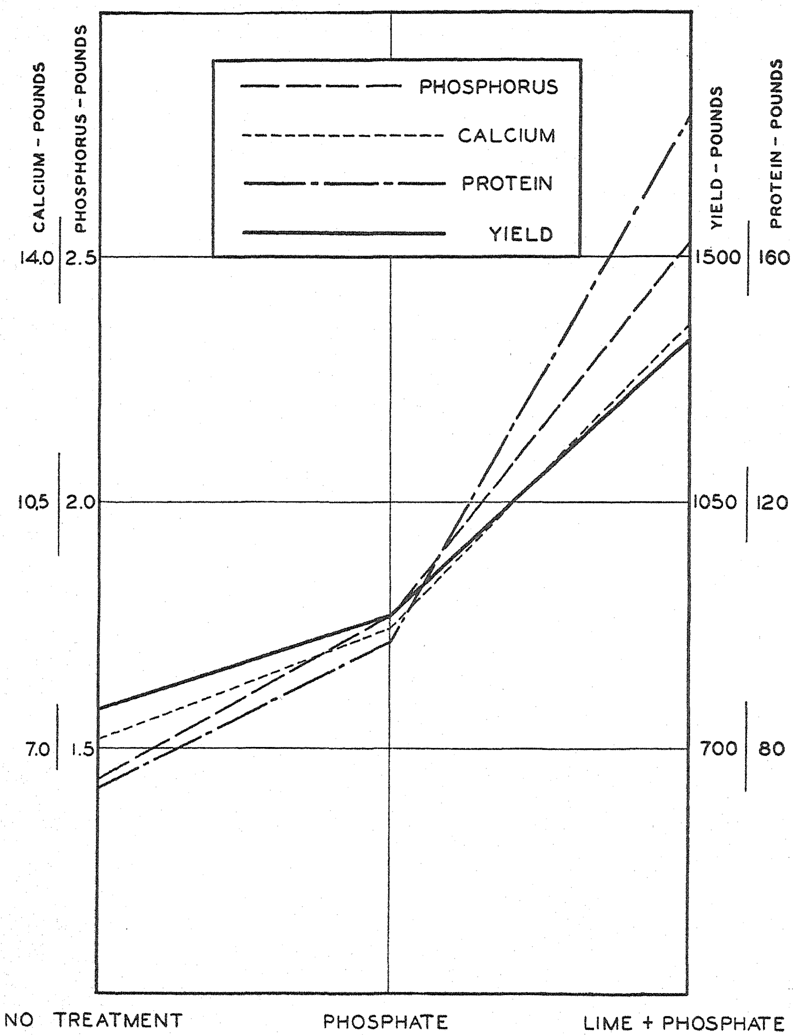

Fig. 1—Nutrient harvest in the lespedeza crop as influenced by superphosphate and by lime and superphosphate combined as soil treatments.

Such increases in forage yields of lespedeza for this one trial in the better season of 1938, and particularly such an increased content in nitrogen, suggest that the efficiency of this legume as a nitrogen fixer may be improved on some soils by the soil treatments of limestone and phosphate. It suggests that on the less fertile soils, such as Putnam silt loam, Korean lespedeza cannot reach its highest efficiency as a soil improver, nor as a feed, without attention to soil treatments. When these consist of limestone and phosphates, they not only give increased crop and nitrogen harvest, but their use together may serve to mobilize the phosphorus into the crop more effectively for an increase in the total crop harvest and in its relative content of protein.

THE NUMBER OF REPLICATED SMALL PLAT TESTS REQUIRED IN REGIONAL VARIETY TRIALS[1]

J. B. HARRINGTON[2]

THE present trend in the comparative testing of new varieties or treatments is toward having a large number of tests well distributed. The many combinations of climatic, soil, and topographical conditions which occur in any large agricultural area are represented very roughly at the best by the results obtained on the existing experiment stations. The station tests give results which apply precisely to only the very limited environments of the stations and therefore serve satisfactorily only the few farmers who reside close by. The remaining farmers, possibly 90% of the total number, have to be satisfied with more or less misleading approximations, unless, in addition to the station tests, supplementary local tests are conducted.

The situation is well illustrated in the Province of Saskatchewan. There are five experiment stations in the Province serving a block of farming country roughly 400 miles by 300 miles with a large diversity of soils and climates and a total of nearly 20,000,000 acres devoted annually to grain crops. It is generally considered that the results obtained at the experiment stations, augmented occasionally by some cooperative tests with farmers, are inadequate, particularly when information on the comparative performance of new varieties is desired urgently by farmers in all parts of the Province.

It is felt that supplementary tests are valuable, but opinions vary considerably as to how many are needed. Considering the cost of the tests, it is desirable to conduct the minimum number that will provide the necessary information. Recently, several hundred well-distributed tests were run in Saskatchewan and the present paper makes use of the data in dealing with the question of how many tests are required.

PROCEDURE

In 1934, the Saskatchewan Wheat Pool, realizing the need for more tests, conceived the ambitious scheme of financing a program of variety testing on a large scale. After considerable effort and expense a series of 355 five-variety latin square tests of barley was conducted in 1935. These tests were so suscecsful that the same organization promoted in 1936, in addition to 50 barley tests, a series of 321 tests of wheat varieties, and in 1937 and 1938 a further 684 tests of wheat varieties. Altogether these series totalled 1,410 tests containing 27,573 plats and 110,292 separately labelled rows.

The summarized data on each successful test of 1935, 1936, and 1937 were published by the Saskatchewan Wheat Pool (3, 4, 5).[3]

[1]Contribution from the Field Husbandry Department, College of Agriculture, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Also presented at The Annual Meeting of The American Society of Agronomy at Washington, D. C., November 18, 1938. Received for publication December 24, 1938.

[2]Professor of Field Husbandry.

[3]Figures in parenthesis refer to "Literature Cited", p. 299. In the publications recognition is given of the assistance of the Dominion Experimental Farms System, the University of Saskatchewan, and particularly the individual farm cooperators.

Throughout the project each test consisted of a compact block of plats each plat comprising four rows 10 feet long and 1 foot apart and protected from end effects by spring sown winter wheat. Each test was sown on summer-fallow under field conditions away from buildings and surrounded by a grain crop. Notes were taken on height, straw strength, neck strength, and date of maturity by the cooperators, only the two center rows of each plat being used. The same rows were later harvested, wrapped, tied, and labelled by plats and sent to experiment stations for the determination of yield, weight per measured bushel, thousand kernel weight, and protein content. The yields were taken in grams per plat (1/2178 acre) and are expressed in the tables in bushels per acre. The cooperators (especially selected farm boys and girls from 15 to 18 years old), while assisted in many cases, worked essentially independently by following detailed mimeographed and printed instructions on how to lay out and carry through a test.

Throughout the tests the latin square method was used. Each year a balanced arrangement identical for all tests of that year was employed. The value of balanced arrangements was emphasized by Gosset (2) in 1936. This arrangement allowed, with no sacrifice of validity, an appreciable saving of expense in the routine procedures of packeting seed, writing labels, threshing the grain, compiling the data, and in the preparation of instructions and report forms. In the barley tests of 1935 a five replicate latin square was used. The 1936 wheat test consisted of a four replicate latin square. In 1937 it was desirable to test six varieties of wheat. With very little sacrifice of precision and a large saving in money the test was arranged in the form of a three replicate modified latin square[4] instead of a four replicate figure. The use of the modified latin square arrangement was referred to by Snedecor (6) in 1934. Fisher's (1) variance method was used to analyze the data on grain yield, the character which will be considered in this paper. The formula $1/N\sqrt{a^2+b^2+c^2, \ldots n^2}$ was used in determining the mean standard error for a series of tests.[5] The standard error of a difference was calculated by the formula $\sqrt{a^2+b^2}$ and this was multiplied by 1.77 to furnish a figure which, if exceeded, would indicate that one variety excelled another by odds of at least 19 to 1.

In the present study the problem was resolved into a search for answers to three questions: How many tests must be made to reveal accurately the comparative merits of the varieties with respect to (a) the Province as a whole, (b) a given cereal variety zone, and (c) a particular condition in or portion of a given cereal variety zone? *The last question is the crucial one* since it concerns directly the large majority of individual farmers.

[4]A latin square with columns more than one plat wide. In this case the three columns were each two plats wide.

[5]This formula takes account of the variability within varieties at each location and its use here is somewhat comparable to using the "remainder" for the estimate of error in a variance analysis including all of the data from the various tests. The necessary differences obtained as a result of using this formula may therefore vary somewhat from the results obtained from the more correct method of comparing the varieties by pairs throughout the sets of tests by "Students" or some other pairing method. However, the work entailed in using a pairing method throughout the study would be enormous and the results would be very cumbersome to present. The "variety x test" interaction, which some biometrical writers have recommended as the correct source of the estimate of error for mean variety differences in tests at several locations has proved quite unsatisfactory for that purpose and therefore is not used here. The writer considers that the method employed is the most feasible one under the circumstances and believes that the errors it introduces are of no practical importance in the present study.

While there is much diversity of soil and climate in Saskatchewan, the Province may be divided fairly definitely into four main soil-climatic zones, *viz.*, (a) the semi-arid open plains, (b) the transitional open plains region, (c) the parked dark soil area, and (d) the forest lands. For purposes of grain variety recommendations, the soil-climatic zones have been divided into cereal variety zones designated by the soil-climatic zone number plus a letter.

RESULTS OF 1935 BARLEY TESTS

Of the 355 barley tests sown in 1935, a total of 261 were considered to be reliable for biometrical analysis. There was a large range of variation among the tests. The standard error of the mean yield of a variety in percentage of the mean yield of the test ($SEv\%$) was distributed as follows: 82 were 2 to 4%, 103 were 5 to 7%, 44 were 8 to 10%, 6 were 14 to 16%, 5 were 16 to 19% and 3 were 20 to 22%. The $SEv\%$ was below 5% in 31.4% of the tests. The average $SEv\%$ for all tests was 6.9%. These errors, while higher than most of those at experiment stations, somewhat comparable station tests at Saskatoon in 1935 averaging 5.3%, compared fairly favorably with them. The range in yield within tests had the following distribution.

Range in bushels:	1–8	9–16	17–24	25–32	33–40	41–48	49–56	57–64
No. of tests:	21	62	109	44	15	5	4	1

The mean range in yield per test was 20.7 bushels per acre. The distribution of yield differences necessary to provide odds of 19 to 1 that one variety excelled another was:

Yield difference in bushels	2–4	5–7	8–10	11–13	14–16	17–19
No. of tests:	46	123	61	19	8	4

The mean necessary difference was 7.05 bushels per acre.

PROVINCE-WIDE BASIS

Considering the Province as a whole, How many tests seem desirable? Different numbers of tests were taken at random from the entire 261 tests and the averages compared. Altogether 12 random sets of 5 tests, 6 of 10 tests, 5 of 20 tests, 2 of 40, and 2 of 80 were studied. The results appear in Table 1. The sets of 5 tests varied considerably from each other and from the average for the 261 tests (set 28), but 10 of the 12 sets had the same yielding order of varieties as set 28 and the significant varietal differences of set 28 were matched in 24 out of 36 comparisons in the 5 test sets. The agreement of each set with set 28 is noted in the last column of the table. In several cases a difference in one set was significantly different from the corresponding difference in another set.

The 10-test sets showed less variation and better agreement with set 28 than the 5-test sets. In each of five of the six sets one variety comparison lacked significance, whereas in set 28 all comparisons were highly significant. The sets of 20 tests agreed well with set 28 except for one comparison in set 20. The 40- and 80-test sets all agreed reasonably well with set 28.

To summarize, all sets of 40 tests or more may be said to have represented the whole Province satisfactorily.

TABLE 1.—*Summarized yields in bushels per acre and in percentage of Regal of four barley varieties in 261 five-replicate plat tests distributed over Saskatchewan in 1935, with comparison of results from different assortments of random sets of tests.*

Set	No. of tests	Summarized yields for each set							Neces-sary diff., bu.*	Agree-ment with set 28†
		Regal, bu.	Trebi		OAC 21		Colsess			
			Bu.	%	Bu.	%	Bu.	%		
1	5	34.2	42.8	125	27.6	81	30.6	89	2.57	P
2	5	60.1	69.4	115	51.6	86	50.6	84	3.08	P
3	5	31.0	41.4	134	28.6	92	31.2	101	2.06	P
4	5	33.2	39.2	118	29.2	88	33.2	100	2.43	P
5	5	40.2	48.2	120	35.8	89	39.4	98	1.92	F
6	5	38.4	46.8	122	35.2	92	39.0	102	2.08	P
7	5	40.6	49.2	121	35.6	88	38.2	94	2.03	F
8	5	40.0	42.4	106	33.0	83	33.2	83	2.84	P
9	5	29.2	38.8	133	26.2	90	27.8	95	2.35	F
10	5	41.2	51.6	125	37.0	90	33.8	82	3.97	VP
11	5	51.6	69.6	135	45.4	88	47.4	92	3.31	F
12	5	27.6	33.6	122	24.2	88	24.4	88	2.29	P
13	10	39.3	47.5	121	35.5	90	39.2	100	2.00	P
14	10	40.3	45.8	114	34.3	85	35.7	89	1.59	G
15	10	40.3	54.2	134	36.0	89	37.6	93	1.41	F
16	10	34.5	42.6	123	30.6	89	29.1	84	1.75	P
17	10	47.2	56.1	119	39.6	84	40.6	86	2.30	G
18	10	32.1	40.3	126	28.9	90	32.2	100	2.00	F
19	20	39.8	46.7	117	34.9	88	37.5	94	1.35	F
20	20	37.4	48.4	129	33.3	89	33.4	89	1.83	F
21	20	43.8	55.2	126	37.8	86	39.1	89	1.22	G
22	20	40.4	48.2	119	35.6	88	38.6	96	1.59	F
23	20	39.9	48.2	121	34.3	86	36.4	91	1.54	G
24	40	38.6	47.5	123	34.1	88	35.4	92	0.95	VG
25	40	40.1	48.2	120	34.9	87	37.5	94	0.92	VG
26	80	39.4	47.9	122	34.5	88	36.5	93	0.66	VG
27	80	36.4	47.0	129	32.6	90	33.9	93	0.66‡	VG
28	261	37.8	46.4	126	33.0	92	34.6	95	0.50‡	—

*Necessary difference is the difference required for odds of at least 19:1 that one variety yielded more than another. If the reader prefers to use odds of 40 to 1 in this or in any of the other tables the necessary differences as given should be increased by 13%.
†Agreement with set 28: P =poor; F =fair; G =good; VP =very poor; VG =very good.
‡Estimated.

ZONE BASIS

Some of the larger cereal zones contain annually more than 3,000,000 acres of grain crops and it is important that accurate information on varietal performance in each zone and even in different parts of the same zone be obtained. Here again the question arises, How many tests are necessary?

Two random lots of 10% of the total number of tests in a zone and the combination of these two sets, or 20% of the total number, were taken for each zone. The results are given in Table 2. These results may be summarized as follows: There was significant disagreement between random lots and zone averages in 15 cases out of 24 concerning the 10% randoms and in 6 cases out of 12 concerning the com-

bination or 20% randoms. Although more reliable than the smaller randoms, the 20% randoms were misleading in half the cases which

TABLE 2.—*Average yields in bushels per acre of four barley varieties in 261 five replicate plat tests distributed over Saskatchewan in 1935, with results from random groups of sets compared with the average results from each zone.*

Variety	Random sets of tests				Random sets of tests				Random sets of tests			
	1st	2nd	Both	All tests	1st	2nd	Both	All tests	1st	2nd	Both	All tests
	Zone 1A				Zone 1B				Zone 2A			
No. tests	2	2	4	22	2	2	4	21	4	4	8	38
Regal	47	40	43	31	41	21	31	29	35	37	36	30
Trebi	60	62	61	41	46	31	38	38	50	48	49	45
OAC 21	45	41	43	29	24	17	20	26	37	42	39	30
Hannchen*	43	34	38	31	—	—	—	—	—	—	—	—
Colsess	49	40	45	31	33	24	28	27	38	39	38	32
Nec. diff., bu.	4.4	6.5	3.9	1.4	4.8	5.0	3.5	1.2	2.3	3.0	1.9	0.9
Agreement†	P	VP	VP		P	P	P		G	P	F	
	Zone 2B				Zone 2C				Zone 3A			
No. tests	6	6	12	63	1	1	2	7	2	2	4	18
Regal	38	38	38	37	22	26	24	30	26	23	24	25
Trebi	49	48	48	45	58	31	45	43	44	43	43	38
OAC 21	29	36	33	31	30	16	23	27	32	34	33	28
Colsess	37	37	37	36	31	27	29	34	31	23	27	26
Nec. diff.	3.0	2.3	1.9	0.9	5.9	4.0	3.5	2.1	3.2	3.7	2.5	1.2
Agreement†	P	G	VG		P	F	G		G	P	P	
	Zone 3B				Zone 3C				Zone 3D			
No. tests	1	1	2	3	2	2	4	25	1	1	2	6
Regal	36	34	33	42	31	59	45	50	57	53	55	45
Trebi	46	44	45	48	35	68	51	59	65	51	58	49
OAC 21	35	35	35	42	28	50	39	44	54	34	44	35
Colsess	27	26	27	31	27	44	35	41	43	37	40	37
Nec. diff.	6.1	11.7	6.5	6.7	3.1	6.1	3.4	1.3	4.5	6.5	3.9	2.3
Agreement†	P	G	F		G	G	VG		P	P	P	
	Zone 3E				Zone 4A				Zone 4B			
No. tests	3	3	6	27	2	2	4	21	1	1	2	10
Regal	38	37	38	31	69	42	55	52	42	38	40	38
Trebi	41	44	43	37	67	55	61	63	61	46	54	44
OAC 21	30	31	31	26	64	40	52	48	42	46	44	37
Colsess	32	34	33	29	44	44	44	44	30	47	39	37
Nec. diff.	2.1	2.7	1.7	1.1	5.7	4.3	3.6	1.6	6.7	5.9	4.4	1.9
Agreement†	G	G	VG		VP	P	F		VP	VP	P	

*Hannchen, alternating with Peatland as the fifth variety, happened to be in all tests in Zone 1A.
†Agreement with average of all tests. P = poor; F = fair; G = good; VP = very poor; VG = very good.

clearly indicates the need of more tests than 20% of the number carried; that is, more than 52 tests for the whole Province.

BASIS OF LOCAL CONDITIONS

Perhaps one of the most valuable results of having a large number of tests is the fact that some of the tests reveal certain important varietal differences which may be obscured or missing in a small number of tests. The data were therefore studied to see whether the large number of tests were justified on the basis of contributing information not otherwise obtained, or, if obtained, not significant or not clearly observable. This study included the data from five zones.

In zone 1A, five random lots of 4, 8, and 12 tests were taken. Only the 12-test random gave an accurate picture of the zone results. Some parts of the zone suffered drought while other parts had good rainfall. The five lowest yielding tests were taken in comparison with the five highest yielding ones. Since the low yields were undoubtedly due to drought conditions (the tests were sown reasonably early on summer-fallow), these tests indicate the relative drought resistance of the varieties. The two sets differed significantly, the results indicating that Hannchen, Colsess and, to a certain extent, Trebi, were more resistant to the drought than OAC 21 and Regal whereas the latter two prospered relatively more under favorable conditions. Even the 12-set random did not include enough tests of these two sets to reveal the comparison clearly. The results are shown in Table 3.

TABLE 3.—*Average yield for different sets of tests in bushels per acre and in percentage of Regal for results from Zone 1A.*

Variety	5 low tests		5 high tests		Random 4 tests		Random 8 tests		Random 12 tests	All 22 tests	
	Bu.	%	Bu.	%	Set 1 %	Set 2 %	Set 1 %	Set 2 %	%	Bu.	%
Regal	15	100	58	100	100	100	100	100	100	31	100
Trebi	22	146	64	110	142	137	139	127	133	41	132
OAC 21	11	76	54	94	100	94	97	96	97	29	94
Hannchen	19	126	52	90	88	123	103	112	103	31	100
Colsess	17	118	47	81	105	100	102	99	101	31	100
Nec. diff.	1.9		4.2							1.4	
Agreement with all*					P	P	G	P	G		

*P = poor; G = good.

Similar studies were made of the results for zones 3A and 3C without striking results. For these zones possibly a quarter as many tests as were run would have been sufficient to represent the zones clearly.

A study of zone 2A results was made on the basis of different soil types. The results are given in Table 4. The supremacy of Trebi was significantly greater on the Regina clay, a lacustrine soil, than on the Weyburn loam, a glacial soil. Regal was very significantly outyielded by OAC 21 and Colsess on the Regina clay, but the three varieties yielded about alike on the Weyburn loam. These differences

were not obtained in either the four-test randoms nor in the combination eight-test randoms. In fact, the random eight happened to include only 1 of the 10 tests of the two special groups discussed.

TABLE 4.—*Average yields for different sets of tests in Zone 2A in bushels per acre and in percentage of Regal.*

Variety	Random sets						Five typical tests on				All 38 tests	
	4 tests		4 tests		8 tests		Regina clay		Weyburn loam			
	Bu.	%	Bu.	%	Bu.	%	Bu.	%	Bu.	%	Bu.	%
Regal	35	100	37	100	36	100	22	100	23	100	30	100
Trebi	50	143	48	130	49	136	57	264	35	151	45	150
OAC 21	35	101*	31	85	33	93	27	127	24	93	30	100
Colsess	38	109	37	99	37	104	34	157	23	99	32	107
Nec. diff.	2.3		3.0		1.9		2.5		1.7		0.9	

*OAC 21 yielded 0.3 bu. more than Regal.

Zone 2B, being large, furnished material for several assortments of sets from among the total of 63 tests. This zone is 265 miles from northwest to southeast and 110 miles wide at the widest part. One 12-test random and four special groups of tests were studied. The summarized data are given in Table 5.

TABLE 5.—*Average yield for different sets of tests in Zone 2B in bushels per acre and in percentage of Regal.*

Nature of tests	Regal		Trebi		OAC 21		Colsess		Nec. diff., bu.
	Bu.	%	Bu.	%	Bu.	%	Bu.	%	
All 63	37	100	45	122	31	84	36	97	0.9
Random 12	38	100	48	126	33	89	37	97	1.9
Five light soil	36	100	41	115	23	65	36	102	2.7
Five western	31	100	37	116	23	73	28	88	3.0
Five southeast	53	100	59	111	50	94	49	91	3.8
Five lowest yield	12	100	21	172	11	90	19	152	1.3

In the group of five lowest yielding tests, Trebi and Colsess yielded 72% and 52%, respectively, above Regal compared with 22% and 0% above, respectively, in the 63-test averages for the zone. These low yield tests reveal the superior drought resistance of Trebi and Colsess as compared with Regal and OAC 21. No indication of this superiority was obtained from a random set of 12 tests. The group of five tests taken from a central light soil area showed OAC 21, unlike the other three varieties, to be very significantly lower in yield than in the zone average. The five southeast tests show an OAC 21 vs. Colsess difference which was significantly different than the OAC 21 vs. Colsess difference in the zone averages. It is apparent that having a large number of tests in zone 2B furnished information which might easily have escaped notice or else been of no significance if the number of tests had been materially less.

Summarizing, the work on the 1935 results shows that (a) as few as 20% of the tests represented the Province satisfactorily, that (b) about 20 to 50% of the tests were required to represent a cereal zone accurately, and that (c) all or nearly all of the 261 tests were needed to reveal the relationships of the varieties under particular conditions or in certain definite parts of the cereal zones.

RESULTS OF THE 1936 WHEAT TESTS

Of the 321 wheat tests of 1936, 194 were successful. These tests were for the purpose of comparing the new stem rust resistant variety Thatcher with well-known standard varieties in all parts of the Province. The results for the three varieties which were in all tests (the fourth variety was one of Garnet, Ceres and Reliance according to the location of the test) are given by zones in Table 6. The varieties did not have constant yield relationships in the different zones. For example, Marquis was relatively at its best in zones 1, 3C, and 3D where Reward was relatively at its poorest. Again, Thatcher yielded much more in relation to Marquis in zones 2A and 3B than in zone 1, indicating that Thatcher was less able than Marquis to do well under drought conditions.

TABLE 6.—*Summarized yields in bushels per acre and in percentage of Marquis of three wheat varieties in 192 four-replicate plat tests distributed throughout Saskatchewan in 1936.*

Zone	No. of tests	Marquis		Thatcher		Reward		Nec. diff., bu.
		Bu.	%	Bu.	%	Bu.	%	
1	46	10.2	100	11.3	111	8.9	87	0.31
2A	17	15.4	100	18.6	121	14.9	97	0.61
2B	41	16.2	100	18.9	117	15.5	96	0.52
2C	2	2.5	—	4.0	—	4.5	—	0.72
2	60	15.5	100	18.3	118	14.9	96	—
3A	14	19.2	100	22.7	118	19.4	101	0.94
3B	8	23.0	100	28.9	126	22.3	97	1.14
3C	23	25.0	100	28.4	114	20.8	83	0.95
3D	10	24.6	100	27.8	113	20.8	85	0.87
3E	27	16.8	100	19.9	118	15.7	93	0.73
3	82	21.7	100	25.5	118	19.8	91	—
4A	3	19.0	100	22.0	116	17.3	91	1.83
4B	3	12.7	100	14.7	116	13.0	102	2.50
4	6	15.9	100	18.4	116	15.2	96	—
Province	194	16.7	100	19.4	116	15.3	92	0.23

A detailed study of results from different numbers of tests taken at random from two of the large zones was made. The results on zone 1 are given in Table 7. In zone 1 it was found that three 10-test randoms agreed only fairly well with the 45-test average, whereas a 20-test random agreed very well. The ability of Reward to do as well as Marquis under some severe drought conditions was revealed by the 10 highest and 10 lowest yielding tests. When as few as 23 of the 45 tests were taken, this relationship was not clear cut as only 3 of the low-yielding tests were included.

TABLE 7.—*Summarized yields in bushels per acre of four wheat varieties in 45 four-replicate plat tests in Zone 1 in 1936, with comparison of results from different assortments of random tests.*

Set	No. of tests	Description of tests	Marquis, bu.	Reliance, bu.	Thatcher, bu.	Reward, bu.	Nec. diff., bu.	Agreement with set 1
1	45	All zone	10.2	11.2	11.2	8.8	0.31	——
2	2	Random	11.0	13.0	15.0	11.0	1.20	Poor
3	2	Random	5.5	7.5	8.0	8.5	1.34	Poor
4	2	Random	18.5	18.0	17.5	15.5	1.57	Poor
5	5	Random	14.4	15.0	14.6	12.0	0.78	Good
6	5	Random	10.8	12.4	12.8	10.4	0.99	Fair
7	5	Random	7.0	9.2	8.8	7.0	1.00	Fair
8	5	Random	6.6	7.2	7.2	6.2	0.56	Fair
9	10	Random	12.6	13.7	13.8	11.2	0.63	Good
10	10	Random	6.8	8.2	8.0	6.6	0.57	Fair
11	10	Random	9.8	10.0	10.1	8.7	0.81	Fair
12	20	Random	9.7	11.0	10.9	8.9	0.42	Good
13	10	High yield	18.3	19.3	19.5	14.7	0.78	Good
14	10	Low yield	4.3	4.7	5.0	4.5	0.50	Poor

The data for zone 2B were sampled on the basis of sub-zones as this zone contains some widely different examples of the transitional soil-climatic area between the open plains and the park lands. The results are presented in Table 8. The total of 41 tests was represented poorly to fairly well by three of the random sets of 10 tests. A random set of 20 tests agreed well with the zone averages. The 41 tests of the zone were then divided into four sections on a geographic basis. Marquis and Thatcher were significantly closer together in yield in the north and west portions than in the southeast or the southwest divisions, again indicating that Marquis could do better relatively

TABLE 8.—*Summarized yields in bushels per acre of five wheat varieties in 41 four-replicate plat tests in Zone 2B in 1936. Comparison of results from different assortments of random tests and in different zone subdivisions.*

Set	No. of tests	Description of tests	Marquis, bu.	Ceres, bu.	Thatcher, bu.	Reward, bu.	Reliance, bu.	Nec. diff., bu.	Agreement with set 1
1	41	All zone	15.9	—	18.8	15.5	—	0.52	——
2	5	Random	17.8	—	19.8	14.8	—	1.19	Poor
3	5	Random	16.4	—	18.4	16.8	—	1.10	Poor
4	10	Random	17.1	—	19.1	15.8	—	1.35	Fair
5	10	Random	18.4	—	22.9	20.3	—	0.84	Poor
6	10	Random	15.8	—	17.3	13.5	—	0.76	Fair
7	20	Random	17.1	—	20.1	16.9	—	0.79	Good
5	13	Southwest	17.0	—	21.1	17.4	18.9	0.84	——
6	2	Random	20.5	—	22.5	20.5	23.5	3.96	Poor
7	4	Random	15.8	—	18.0	13.0	16.3	1.10	Poor
8	10	Southeast	23.5	26.8	28.4	23.2	—	1.30	——
9	2	Random	18.0	17.5	20.0	16.5	—	1.23	Poor
10	4	Random	23.5	25.8	28.5	26.8	—	1.59	Poor
11	12	North	13.0	13.9	13.9	12.0	—	0.94	——
12	6	West	6.5	7.5	7.5	5.7	—	0.96	——

than Thatcher under dry conditions. Small randoms (of 15 and 30%, respectively) from the southwest and southeast sections agreed poorly with the section totals.

Summarizing, the work on the 1936 results shows that (a) nearly half of the tests were needed to represent a zone satisfactorily and that (b) all or nearly all of the tests were needed in order to obtain accurate comparative variety reactions to specific conditions or in local areas.

RESULTS OF 1937 WHEAT TESTS

The 1937 wheat tests were of particular interest because they carried all three of the new highly stem rust resistant varieties Apex, Renown, and Thatcher, the first two not having been placed previously in widespread farm-cooperator tests. The drought in the open plains region was the most severe on record and of the 334 tests sown only 136 were successful. Table 9 shows by zones the summarized results on five of the varieties.

TABLE 9.—*Summarized yields in bushels per acre and in percentage of Marquis of five wheat varieties in 136 three-replicate plat tests distributed throughout Saskatchewan in 1937.*

Zone	No. of tests	Marquis, bu.	Reward		Thatcher		Apex		Renown		Nec. diff. bu.
			Bu.	%	Bu.	%	Bu.	%	Bu.	%	
1	9	5.8	4.5	78	5.8	100	5.7	98	4.5	78	0.52
2A	8	6.5	5.6	86	6.9	106	6.8	105	5.5	85	0.50
2B	25	6.0	4.6	77	6.9	115	6.1	102	5.3	88	0.46
2C	0	—	—	—	—	—	—	—	—	—	—
2	33	6.1	4.8	79	6.9	113	6.2	102	5.3	87	—
3A	16	11.2	10.3	92	13.5	121	11.2	100	11.0	98	0.74
3B	9	20.5	17.1	83	22.8	111	20.6	100	19.6	96	1.02
3C	25	16.5	13.6	82	18.9	115	16.6	101	15.7	95	0.89
3D	12	21.7	21.8	100	25.1	116	23.3	107	20.9	96	1.21
3E	24	11.0	9.3	85	12.6	115	11.7	106	11.2	102	0.73
3	86	15.1	13.3	88	17.5	116	15.6	103	14.7	97	—
4A	7	29.0	26.0	90	33.0	114	31.9	110	29.0	100	2.24
4B	3	16.3	14.0	—	17.0	—	15.3	—	14.3	—	3.16
4	10	25.2	22.4	89	28.2	112	26.9	107	24.6	98	—
All	138	13.2	11.4	86	15.1	114	13.6	103	12.6	95	0.30

The tests proved to be excellent for revealing the relative behavior of the varieties under a range of conditions varying from extreme drought to favorable situations. In zone 1, Reward and Renown did poorly compared with Marquis. Thatcher, usually well above Marquis, was equal to it in this zone and Apex maintained equality with Marquis. Apex alone had sufficient drought resistance to approach its normal yield relative to Marquis. The nine successful tests in zone 1 were the result of sowing 105 tests. If only a portion of these tests had been sown it is probable that the number of successful ones would have been too small to furnish comparisons of any significance.

Renown did definitely better in the park and forest area (zones 3 and 4) than on the open plains (zones 1 and 2). Thatcher appeared to

excel Renown in adaptation, doing well not only in zones 3 and 4 but also in much of zone 2. Thatcher, however, proved distinctly less able than Marquis to do well under severe drought conditions, although showing greater adaptability than Reward, as in 1936. Apex proved the most adaptable of the three by yielding well in all zones. The adaptation comparison is brought out by the variation in yield of each variety in percentage of Marquis, *viz.*, Renown, 24%; Thatcher, 21%; and Apex, 12%.

Summarizing the 1937 results, it appears evident that the number of tests in the open plains zones was not unnecessarily large. In most of the other zones it appeared desirable to have all or nearly all of the tests that succeeded. In two zones there were too few tests to be of real value.

PROPORTION OF SUCCESSFUL TESTS

Table 10 shows a statistical summary of all of the tests according to cereal variety and soil-climatic zones. In the Province as a whole the highest proportion of successful tests was in the favorable season of 1935, the next highest in the dry season of 1936, and a decidedly lower percentage in the very dry season of 1937. Zone 4, the moist forest area, showed its highest proportion of successful tests, 91% in 1937, when the drought was so severe in the open plains region that the proportion of successes in zone 1 was only 9% and in zone 2 only 32%. As the three years were drier than the long time average, the average proportion of successful tests, 58.7%, is a very conservative estimate of the proportion of tests likely to be satisfactory in future testing programs of this kind. The results indicate that, in the appor-

TABLE 10.—*Statistical summary of the number of individual cooperative tests and percentage of successful test in each year in both the cereal variety and the soil climatic zones.*

Zone	1935			1936			1937			% satisfactory tests, 3 yrs.
	No. of tests	Satisfactory tests		No. of tests	Satisfactory tests		No. of tests	Satisfactory tests		
		No.	%		No.	%		No.	%	
1	86	43	50	98	46	47	105	9	9	33.9
2A	51	38	75	40	17	55	36	8	22	53.5
2B	76	63	83	55	41	65	61	25	41	64.6
2C	8	7	88	7	2	29	7	0	0	40.9
2	135	108	80	102	60	59	104	33	32	58.9
3A	22	18	82	19	14	74	20	16	80	78.7
3B	4	3	75	10	8	80	12	9	75	76.9
3C	33	25	76	32	23	72	33	25	76	74.5
3D	7	6	86	12	10	83	15	12	80	82.4
3E	32	27	84	40	27	68	34	24	71	73.6
3	98	79	81	113	82	73	114	86	75	76.0
4A	23	21	91	4	3	75	7	7	100	91.2
4B	13	10	77	4	3	75	4	3	75	76.2
4	36	31	86	8	6	75	11	10	91	85.5
Province	355	261	74	321	194	60	334	138	41	58.7

tionment of tests, three times as many should be sown in areas like zone 1 as are required in a completed form, whereas in areas like zone 4 for every six sown five may be expected to succeed.

DISCUSSION

Having a large number of replicated tests distributed over an agricultural region has certain definite advantages compared with using a small number of tests. One of these advantages is the greater reliability of the information obtained. Another advantage is the reduction in the estimate of error giving significance to smaller differences. A third advantage is that many tests reveal clearly the distinctive behavior of the varieties under certain seasonal conditions as well as in particular soil-climatic environments. The only important disadvantage is the greater expense of a large number of tests.

Since the principal purpose of tests of different varieties or treatments which are available to the farmer is to furnish information which will be valuable in advising him, it is obvious that an insufficient number of tests or a poor distribution of them is not satisfactory. When tests are placed systematically throughout an area the problem of distribution is taken care of. But the problem of number of tests is not solved until sufficient tests are run to provide an accurate answer to the agronomic aspect of a given farmer's question, "What variety (fertilizer, method, etc.) shall I use?" no matter in what local area that farmer lives. The results of the present study indicate that, in a large agricultural region served by five experiment stations, a total of more than a thousand variety tests sown during a 3-year period did not result in an unnecessarily large number of successful tests.

It appears that in order to have a certain number of successful tests in a given area, consideration should be given to the soil and climatic conditions of that area as well as to any unusual limiting factors. It is almost inevitable that a proportion of the tests will be destroyed by crop pests, drought, and other factors not under perfect control.

The number of tests required depends upon the objects of the tests. *From this study it would seem that in order to ascertain quickly the comparative performance of new varieties of an important crop in the different parts of a large agricultural area, literally hundreds of tests should be run for at least two representative years.*

SUMMARY

1. A study was made of data from several hundred replicated small plat tests of barley and wheat to determine the number of tests required for accurate comparative results in a given area. The tests studied were distributed throughout the farming area of Saskatchewan and totalled 27,573 plats, each plat consisting of four 10-foot rows.

2. For the Province as a whole random lots of 40 tests gave close approaches to the results obtained with 261 tests (1935 results).

3. For separate soil-climatic and cereal variety zones a quarter to a half as many tests as run in 1935 and 1936 gave results similar to

those from the larger numbers, except that differences were less frequently significant. The drought in 1937 reduced the number of satisfactory tests to 138 and in only three zones could the number that year be considered larger than necessary.

4. For sampling of local areas within zones results obtained from distinctly fewer tests than those run did not reveal or bring out differences that otherwise were found. Similarly, the differential reactions of the varieties to particular conditions were not shown clearly where small numbers of tests were used.

5. It was concluded that the number of cooperative tests run in Saskatchewan in 1935 to 1937 was not excessive and that materially reducing the number of such tests would have been detrimental to the purpose for which they were planned.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 5. 1934.
2. GOSSET, W. S. Cooperation in large scale experiments. Supplement to Jour. Roy. Stat. Soc., 3:115–122. 1936.
3. SASKATCHEWAN COOP. WHEAT PRODUCERS, LTD. Barley varieties in Saskatchewan, 1935. Regina, Sask. 1937.
4. ————. Junior cooperative wheat variety tests, 1936. Regina, Sask. 1937.
5. ————. Wheat varieties in Saskatchewan, junior cooperative tests, 1937. Regina, Sask. 1938.
6. SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Co-variance. Ames, Iowa: Collegiate Press. 1934.

SOIL-CONSERVING AND SOIL-IMPROVING CROP ROTATIONS FOR THE PALOUSE[1]

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THIS paper deals with the problem of the introduction and establishment of soil-conserving and soil-improving crop rotations in the Palouse of eastern Washington and adjacent Idaho. The information presented has been developed from the demonstration project of the Soil Conservation Service located on the South Fork of the Palouse River in the vicinity of Moscow, Idaho, and Pullman, Washington.

The Palouse is a relatively new country having been plowed out of prairie only a little more than five decades ago. Large scale operations are employed on the crop land which constitutes approximately 75% of the total acreage (7, 8).[3] A typical farm unit has been about 500 acres divided into two major fields. Farm cropping systems have been largely soil depleting, conducive to erosion and accelerated run-off. Soil loss through erosion and decline in fertility have simultaneously progressed under past systems of management to the extent that productivity has decreased and approximately one-fifth of the cultivated land is submarginal for cash crops. Soil-conserving and soil-improving rotations in combination with crop residue utilization and improved methods of tillage have been found to be the most important means of checking these conditions. Terracing and strip-crossing had not been applied to the area because of topography, farming methods, and limited diversity of crops. Soil conservation is being accomplished by treatment of the soil itself to enable it to absorb and store the moisture it receives.

DESCRIPTION OF THE AREA

McGrew and Horner (2) state that, "The typical Palouse topography consists of a series of somewhat dune-shaped loessial hills, which, in general, have south and southwest slopes that are longer than and not so steep as the north and northeast slopes. A considerable part of the cultivated land has slopes ranging from 10 to 40 %. Some of the land has more than 50 % slopes. A characteristic feature of this topography is the steep amphitheatre-like north and northeast slopes. Narrow valleys of alluvial land make up a well-defined drainage system."

The area lies at an approximate elevation of 2,700 feet.

The normal precipitation at Pullman, Wash., based on records over a period of 43 years, is 20.75 inches. However, only about 79% of this is effective moisture as 21% is lost immediately as run-off (2).[4] The annual rainfall has varied from

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Also presented at the annual meeting of the Society held in Washington, D. C., November 16, 1938. Received for publication December 27, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 313.

[4]Four-year average (1932–35) from 2.3 acre watershed cropped to a wheat-fallow system.

14.12 inches in 1935 to 30.87 inches in 1927. Approximately 76% of the precipitation falls from September 1 to March 31. Snowfall occurs intermittently from December 1 to March 1, but total accumulation seldom exceeds 20 to 24 inches. The peculiar dune-like topography and prevailing winds from the southwest are conducive to severe snowdrifting. The snow is blown from the south slopes and hilltops and is piled up on the upper part of the leeward slopes (3). A considerable amount of soil is carried with the snow. These drifts on the north slopes cause an uneven distribution of winter moisture.

Erosion over the Palouse area is caused principally by run-off from rains and melting snow. Most of it occurs during the winter and spring seasons. January, February, and March are the critical erosion months. Combinations of frozen ground, snow, rain, and chinook winds contribute to severe erosion. The average annual soil losses from wheat-fallow land are approximately 9 tons per acre (2).

The soils are predominately of the Palouse series. The following types are of major importance: Palouse silt loam, Palouse silt loam shallow phase, and Palouse silty clay loam shallow phase (2).

Palouse silt loam, the most extensive type, is characterized by a dull dark brown silt loam A_1 horizon of 10 to 12 inches. This is underlain by a brown to yellowish brown silt loam or silty clay loam A_2 horizon to a depth of about 30 inches. The B horizon is a yellowish brown silty clay or silty clay loam and may extend to a depth of 60 inches. This is underlain by a C horizon, a silty-clay loam which is of variable depth and extends to the underlying basalt. The entire profile is quite friable. When dry, the upper horizons show a weakly columnar structure and the subsoil shows a definite columnar structure (2).

The Palouse silt loam shallow phase occurs exclusively on hilltops and ridges where soil-building forces were such that a shallow solum was developed.

The Palouse silty clay loam shallow phase has developed as a result of erosion and downhill movement of soil by tillage operations. True topsoil is lacking, or is so thoroughly mixed with the subsoil that it is entirely indistinguishable.

Before the advent of farming in the area, the Palouse was a rolling prairie country supporting a dense cover of bunchgrasses and legumes. The climax cover was composed chiefly of blue bunch wheat grass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), big bluegrass (*Poa ampla*), and Sandberg's bluegrass (*Poa secunda*). Other associated species were junegrass (*Koelaria cristata*), *Astragalus* spp., *Lupinus* spp., yarrow (*Achillia milifolium*), and balsam root (*Balsamorhiza sagittata*).

CROPS ADAPTED TO THE PALOUSE

Wheat is the most important crop grown in the Palouse. Winter wheat has been grown more extensively than spring wheat although both produce satisfactory yields. Soft white wheats predominate largely because of their yielding capacity. Yields vary considerably, depending upon seasonal climatic conditions and crop sequence, and range between 20 to 50 bushels per acre on average fields (6). The Palouse has never known a crop failure.

Field peas are grown extensively for seed, commercial peas, and livestock feed. The early smooth-seeded variety Alaska is grown almost to the exclusion of other types. The average pea yield is 12 to 14 bushels per acre (6).

Oats and barley are of minor importance in the area. They are usually grown for feed, although a small amount of malting barley is produced. Oats generally produce approximately 60 bushels per acre and barley approximately 30 bushels

(6). Variations, however, are great and yields up to 100 bushels of oats and 60 bushels of barley per acre are not uncommon.

Intertilled crops, including corn, sorghum, cotton, and soybeans, have not been adapted to the area. Climatic conditions and topography definitely limit their use.

In 1938 a considerable acreage of flax and commercial mustard were produced in the area. Previous to this year, mustard was practically unknown and flax has been produced only to a very limited extent.

The entire area is adapted to the production of sweet clover and alfalfa. They have geen grown on a very small proportion of the land and until recently were seldom brought into specific rotations being sown chiefly on conveniently located or favored areas (5).

Alfalfa is used principally for hay and usually produces only one cutting with a yield of 1½ to 3 tons per acre, depending upon site location. Occasionally, alfalfa is left for seed but production is very uncertain. Seed yields vary from a failure to 150 pounds per acre. Hardy variegated alfalfas are produced almost exclusively.

Sweet clover has multiple uses but is most commonly used as green manure or as pasture. To a limited extent it is used for hay and seed production. Tall biennial white sweet clover predominates. As a green manure crop, it produces approximately 10 to 12 tons of green matter per acre. When used for pasture it provides from three to five animal months grazing per acre. As a hay crop it outyields alfalfa about 1 ton per acre. Seed production is more certain than for alfalfa in most years and yields are approximately double.

Grasses have been of minor importance in the area. With the introduction of soil-conserving practices, however, they have assumed major importance. Certain perennial grasses are invaluable for their erosion-resisting properties either in pure stands or in mixtures with legumes. Outstanding grasses today are smooth bromegrass (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), slender wheatgrass (*Agropyron pauciflorum*), tall meadow oatgrass (*Arrhenatherum elatius*), and orchard grass (*Dactylis glomerata*). Other grasses, including ecological strains of native species, are being developed to fill specific needs.

The Palouse is favorably adapted to grass seed production and should rapidly develop into an important source of high quality seed.

PAST CROPPING PRACTICES AND RESULTANT EFFECTS ON SOILS AND EROSION

Comparatively little land was cropped prior to the year 1875. After the Civil War, land was taken up rapidly and during the period from 1880 to 1890 most of the area was plowed and used for wheat production.

Soon after the breaking of the native sod (some 55 years ago) the predominant cropping system was that of continuous grain cropping. Wheat was most commonly produced, but some barley and oats were occasionally grown. The high fertility of the virgin soil was in time reduced by this constant cropping to a point where it was no longer profitable to raise successive grain crops. Accordingly, summer fallow was introduced one year out of three or four in a cycle (4). Within 20 years, by 1900, it became necessary to fallow on alternate years in order to make available a sufficient amount of nitrogen for a profitable grain crop. Fallowing also controlled the annual weeds.

Field peas were introduced about 1918 and by 1930 approximately one-half of the land ordinarily fallowed was diverted to the production of this crop.

In the grain-fallow and grain-pea systems, the soils have been seriously mistreated. Crop residues were generally burned soon after harvest and no crops were grown for soil improvement and fertility maintenance. Under this treatment "the soils have lost at least 35% of their organic matter, 25% of their nitrogen and much of their capacity for absorbing moisture" (6). These soil losses have caused the original open, friable, and mellow condition of the soil to be replaced by a compacted condition. The surface soil under this condition puddles easily and seals over during precipitation periods. The combination of reduced soil organic matter content, less pervious soil, and lack of protective winter cover has resulted in accelerated soil and water losses. Detailed conservation surveys show that most hilltops, ridges, and upper south slopes have lost from 75% to all of their original topsoil. The acreage involved amounts to about 15% of the area. The major part of the area has lost over 25% of its original topsoil. In addition to direct topsoil loss, the washing of gullies through fertile flats and slopes has resulted from the inability of upper slopes to absorb the precipitation they received.

COVER AS RELATED TO EROSION

The degree of resistance against erosion provided by different crops and land treatments within a rotation may arbitrarily be divided into three classes, *viz.*, complete erosion control, semi-erosion control, and no erosion control. In the Palouse area, complete erosion control is that cover condition obtained by close-growing perennial vegetation. This type of cover affords as complete protection against erosion as is economically possible to obtain. Semi-erosion control is that condition obtained by properly utilized grain stubble, standing grain stubble, or a fairly close-growing cover of biennial legumes in pure stands or in mixture with grasses. Properly utilized stubble involves rough tillage and leaving the trash on or mixed with the surface soil. Slight erosion and some water loss may occur on land with this cover condition during the spring run-off period, but protection is afforded against severe soil and water losses. No erosion control is that condition occurring when the land has no protective cover and also has a finely worked surface soil condition. Summer fallow planted to winter wheat and clean-tilled crops are typical examples. This condition permits severe soil and water losses during the critical erosion periods.

The amount of soil and moisture lost from different cover conditions has been quantitatively measured by the Pacific Northwest Soil Conservation Experiment Station at Pullman, Wash. (2). Complete erosion control is represented by an established cover of perennial grass[5] which lost an average of 0.56 ton of soil per acre annually and 2.07% of the total percipitation. Semi-erosion control condition is represented by standing wheat stubble[6] which lost an average of

[5]Only a fair stand.
[6]An average of four stubble conditions.

1.69 tons of soil per acre annually and 5.76% of the precipitation. No erosion control is represented by summer fallow seeded to winter wheat in the fall which lost an average of 16.79 tons of soil per acre and 12.30% of the precipitation.

DEVELOPMENT OF CROP ROTATIONS

The introduction of soil- and water-conserving farming methods into the Palouse required two major changes in farm management. First, it was necessary to introduce soil-building and soil-conserving crops in systematic rotations with a corresponding decrease in summer fallow; and, second, to introduce the use of distinct types of treatments for different soil types, slopes, and erosion conditions occurring in a single large field.

Two classes of rotations were developed to meet the situation, *viz.*, soil-improving rotations and soil-conserving rotations.

Soil-improving rotations are designed for use on fields with gentle slope and slight to moderate erosion (1). Erosion control is effected by the use of green manure crops, crop residue utilization, and improved tillage methods to improve the physical condition of the soil and maintain soil productivity. The three commonly used long-time rotations in this class are (a) sweet clover two years, grain two years, fallow one year, and grain one year; (b) sweet clover and peas one year, sweet clover one year, grain two years, peas one year, and grain one year; and (c) sweet clover two years and grain two years.

As a class, these soil-improving rotations are generally used on Palouse silt loam soils.

Soil-conserving rotations are designed for use on fields with relatively steep slopes and areas of moderate to severe erosion. This class provides a maximum amount of vegetative cover for erosion control in addition to improving the physical condition of the soil and maintaining soil productivity.

The four most common types of rotations in this class are (a) alfalfa and grass four years and grain two years; (b) grass or alfalfa and grass three years and grain three years; (c) sweet clover two years, grass three years, and grain two years; and (d) grass three years, grain two years, sweet clover two years, and grain two years.

As a class soil-conserving rotations are adapted to Palouse silt loam shallow phase and Palouse silty clay loam shallow phase soils although they are oftentimes used on Palouse silt loam soils where slope is excessive or erosion is severe.

EVALUATION OF ROTATIONS FOR SOIL AND WATER CONSERVATION

To evaluate recommended soil-conserving and soil-improving crop rotations, comparison is made with past soil-depleting cropping practices. In this comparison, major emphasis is placed on erosion-controlling values, and secondary emphasis on crop returns.

In the grain-fallow and grain-pea soil-depleting systems, the soil is subject to severe erosion during critical months for at least one year in every two-year cycle. No erosion control is secured during the winter

months after summer fallow or after peas. In both cases, the soil is finely pulverized and puddles easily, which prevents rapid moisture absorption. A combination of these conditions results in heavy run-off accompanied by serious soil loss. Winter wheat planted on fallow or pea land, seldom makes sufficient fall growth to offer resistance

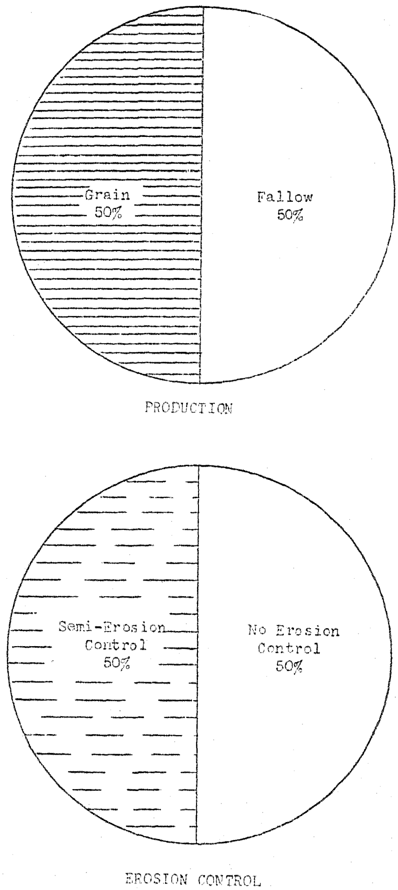

Fig. 1.—Soil-depleting cropping systems. Grain-fallow rotation.

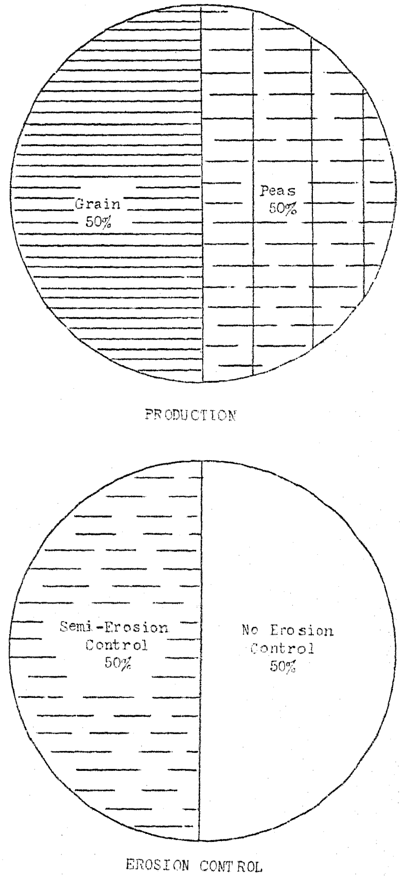

Fig. 2.—Soil-depleting cropping systems. Grain-peas rotation.

against erosion. Semi-erosion control is afforded during the erosion period following grain crops, providing the grain stubble is left standing or is properly utilized. The amount of erosion control afforded by these rotations is graphically illustrated in Figs. 1 and 2. A distinct weakness of both the grain-fallow and grain-pea systems, aside from accelerating erosion, is the fact that they provide income to the farmer from only one source.

In the soil-improving rotations, tall white blossom biennial sweet clover (*Melilotus alba*) is generally used as the soil-improving crop. It may be seeded alone, in a mixture with a perennial grass or with peas as a companion crop, depending upon the soil conditions in the individual field and the amount of erosion control necessary. Sweet clover has multiple uses, but it has its greatest utilization as a dual-purpose crop for pasture and soil improvement. It is also used for hay or seed.

Rotation A is six years in length and includes sweet clover two years, grain two years, fallow one year, and grain one year. The sweet clover is most commonly seeded alone or with grass, as this rotation is used on areas which are not suited to the production of peas. The first-year sweet clover or sweet clover and grass produces a semi-erosion controlling cover. During favorable years, sweet clover and grass may produce cover sufficient to control erosion completely, but such stands are generally fall pastured which reduces their erosion-controlling value. The second year sweet clover is almost always plowed in the fall when the soil is dry. The resulting rough and open soil condition provides a high degree of erosion control. The first crop following is commonly spring sown. Second year sweet clover is consequently classed as semi-erosion controlling.

The effects of the sweet clover soil-improving crop make it possible to produce two successive grain crops following the green manure crop and at the same time produce normal or above normal yields. This combination of sweet clover and annual cropping eliminates two years of summer fallow. The heavy and uniform stubble produced on the fields following sweet clover provides a true semi-erosion controlling condition when properly utilized in the fall or left standing over winter. The year of fallow provides no erosion control. However, the effects of stubble utilization in the previous years, together with the improvement in the physical condition of the soil obtained by the sweet clover crop makes this year markedly less critical than the fallow year in the grain-fallow system. The final grain crop produced in the rotation cycle is similar in erosion control to the two crops produced following sweet clover. This rotation therefore provides five years of semi-erosion control and one year of no erosion control during each six-year cycle. This is graphically illustrated in Fig. 3.

The farm income from this rotation is more nearly balanced than in the case of the previously described soil-depleting systems, owing to the fact that income is secured from both grain production and forage utilization for livestock production.

Rotation B in the soil-improving group is also six years in length and is very similar to rotation A just described. It differs only in that peas are included in the rotation. This rotation is adapted only to better classes of farm land having low erosion potentials. In it, the sweet clover is usually sown with peas as a companion crop and peas also replace summer fallow the fifth year.

Sweet clover seeded with peas is classed as furnishing no erosion control in the fall of the first year, owing to the fact that the stand is inferior to the stand secured when the sweet clover is seeded alone or with grass. Root development of the clover is light and the harvest-

ing operation on the peas cuts the topgrowth almost level with the surface of the soil. Grass is not included with sweet clover and peas because competition of the peas and sweet clover limits its establishment and growth. Although spreading the pea straw at the time of harvesting provides a slight amount of control, soil loss during the

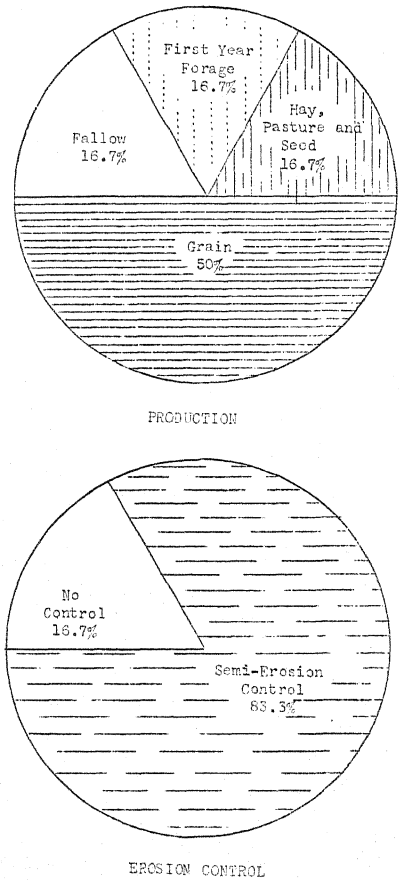

Fig. 3.—Soil-improving rotations. Sweet clover 2 years; grain 2 years; fallow 1 year; and grain 1 year.

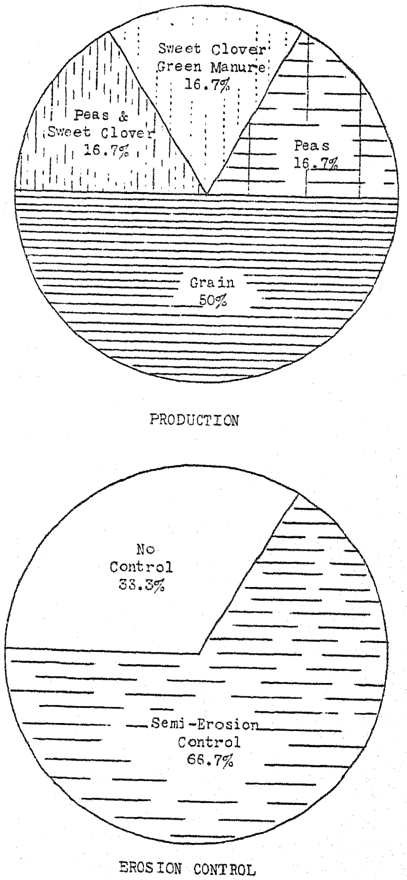

Fig. 4.—Soil-improving rotations. Sweet clover and peas 1 year; sweet clover 1 year; grain 2 years, peas 1 year; and grain 1 year.

following winter months may be severe. The second-year sweet clover in this rotation is generally plowed for green manure at the early blossom stage. The land following the plowing down of sweet clover is in a rough and open condition. If no subsequent tillage is practiced before the winter erosion period, semi-erosion control is provided for that season. The sweet clover is very seldom utilized for hay or pasture because farmers who raise peas extensively usually operate large

units and have few livestock. The two successive grain crops following the sweet clover are comparable to the two grain crops of similar placement in rotation A and provide semi-erosion control. Peas the fifth year of the rotation provide no erosion control as very little cover remains after harvesting on soil that is in a finely pulverized condition due to intensive cultivation in the preparation of the seedbed. The final grain crop provides semi-erosion control. Rotation B, therefore, provides four years of semi-erosion control or two years of no erosion control in every six-year period. This is illustrated in Fig. 4.

Farm income from this rotation is more nearly balanced than in the case of the two-year soil-depleting systems, but in actual practice is less balanced than the six-year sweet clover and grain-fallow system. This is due to the fact that the second-year sweet clover in this rotation is not generally utilized by livestock and, therefore, farm income is chiefly derived from grain and peas.

Rotation C, the third soil-improving rotation, is four years in length and consists of two years of sweet clover and two years of grain. It has been developed for use on the more severely eroded crop land where it is impractical to retire large areas from cereal crop production for long periods of time. Rotation C is also very commonly used on farms where livestock production is of major importance. The sweet clover in this rotation is usually seeded with a perennial grass. Utilization of first-year forage for pasture in the fall is an accepted practice. Second-year sweet clover and grass in this rotation is generally pastured very heavily through the late spring and early summer, and the aftermath is turned under for soil improvement. Fall utilization, however, prohibits classing this as complete erosion control. Second-year sweet clover and grass is usually plowed rough and handled in the same manner as described under rotation A. Both first-year and second-year sweet clover and grass, therefore, are classed as semi-erosion controlling as are the two successive grain crops which follow. Total resistance against erosion is very high consisting of four years of semi-erosion control in each four-year cycle. A graphic illustration is given in Fig. 5. Farm income from this rotation is balanced by livestock production and cereal grain production.

Soil-conserving rotations involve seeding mixtures of alfalfa and perennial grasses or pure seedings of perennial grasses. Alfalfa and grass are almost always used for hay. Pasturing is confined almost exclusively to aftermath. The close-growing cover produced by grass mixtures with alfalfa provides practically complete erosion control. The effect of plowing under alfalfa in preventing erosion persists much longer in the soil than does the effect of plowing under sweet clover. Grass in pure stands in these rotations is ordinarily used for seed production. Mixtures of alfalfa and grass are used in these rotations and are set up so that different seeding rates, different species, and different mixture proportions are closely correlated with soil and erosion conditions.

Rotation A in the soil-conserving class is six years in length and consists of four years of alfalfa and grass and two years of grain. This is the most important rotation in class III because in addition to providing a high degree of erosion control it fits in ideally with the

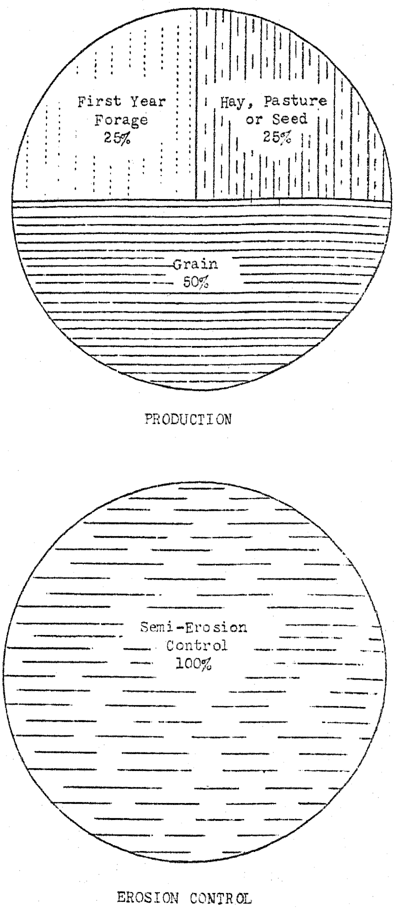

Fig. 5.—Soil-improving rotations. Sweet clover 2 years and grain 2 years.

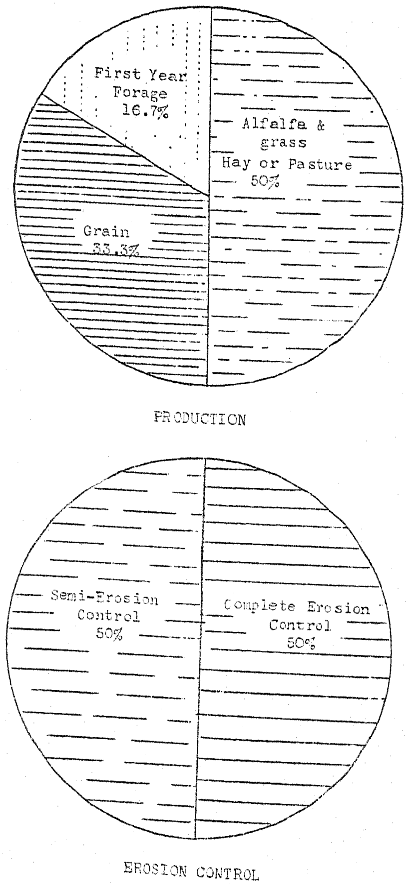

Fig. 6.—Soil-conserving rotations. Alfalfa and grass 4 years; grain 2 years.

six-year sweet clover and grain rotations of class II (a) and (b) previously described. Reference is made to Table 1 showing this relationship.

TABLE 1.—*Relationship between class 2, rotation A and class 3, rotation A, when both are used in a single large field.*

1st yr.	2nd yr.	3rd yr.	4th yr.	5th yr.	6th yr.	7th yr.	8th yr.
Area I							
Fallow	Grain	Sweet clover	Sweet clover	Grain	Grain	Fallow	Grain
Area II							
Alfalfa and grass	Alfalfa and grass	Alfalfa and grass	Alfalfa and grass	Grain	Grain	Alfalfa and grass	Alfalfa and grass

The three years during which a cover of alfalfa and grass are on the field provide complete erosion control. In the fourth year the alfalfa and grass are fall plowed and the soil is left in a rough, open condition during the winter. This provides semi-erosion control. Two successive grain crops are then produced and afford semi-erosion control when the stubble is properly utilized. Erosion control effected by this rotation consists of three years of complete control and three years of semi-erosion control during each six-year period. This is a very great increase over the soil-depleting and erosion-inducing grain-pea or grain-fallow systems, and is also over twice as effective as the soil-improving rotations. A graphic illustration of the amount of erosion control afforded by this rotation is shown in Fig. 6. Income from this six-year alfalfa and grass rotation is very well balanced. The income is derived from cereal grain production, livestock production, and from the sale of hay.

Rotation B in the soil-conserving class is also six years in length and differs from rotation A in that the alfalfa and grass appear only three years in every six. A modification of this rotation includes grass for seed production for three years instead of alfalfa and grass. This rotation is used on areas of slightly less slope and erosion than rotation A. The three successive grain crops following the alfalfa and grass are handled in much the same way as the successive crops following sweet clover.

The third grain crop yields enough to make this system profitable and fallow is thereby entirely eliminated. Erosion control in rotation B consists of two years of complete control, afforded by the first two years of the alfalfa and grass, and of four years of semi-erosion control afforded by one year of rough, fall-plowed alfalfa and grass and by three years of properly utilized grain stubble. Rotation B affords slightly less erosion control than rotation A in the soil-conserving class, but is much superior to any rotation in the soil-improving class. The amount of control is graphically illustrated in Fig. 7.

Rotation C in the soil-conserving class, consisting of two years of sweet clover, three years of grass, and two years of grain, is designed primarily for grass seed production on steep and eroded areas. The two years of sweet clover afford semi-erosion control. The first two years of grass afford complete erosion control, while the year the grass is plowed and the two succeeding years of grain are classed as semi-erosion controlling. This gives two years of complete control and five years of semi-erosion control in each seven-year cycle. The amount of control is graphically illustrated in Fig. 8. This rotation is gaining in importance because of the emphasis being placed on grass seed production in the Palouse. The improvement given the soil by the sweet clover is reflected in very heavy grass seed crops.

Rotation D in this soil-conserving class is nine years in length and consists of three years of grass, two years of grain, two years of sweet clover, and two years of grain. It differs only from rotation B in that a soil-building crop of sweet clover is seeded in the rotation. It differs from rotation C in that the immediate effects of the sweet clover are used for grain production rather than for grass seed production. It has been devised principally to increase or maintain soil fertility and

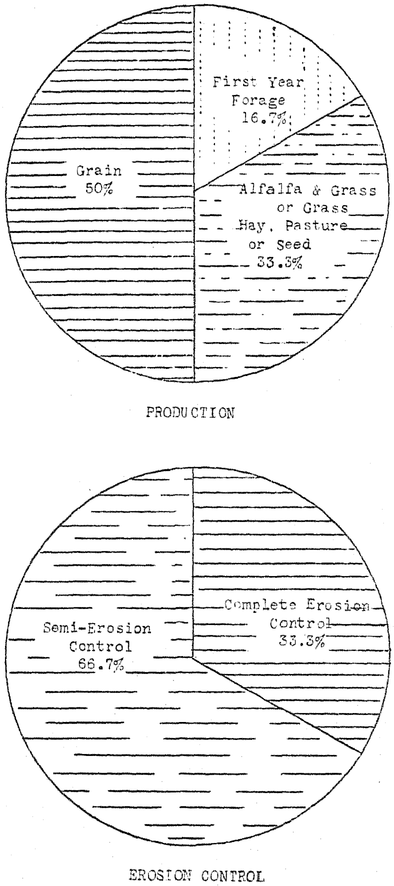

Fig. 7—Soil-conserving rotations. Grass or alfalfa and grass 3 years and grain 3 years.

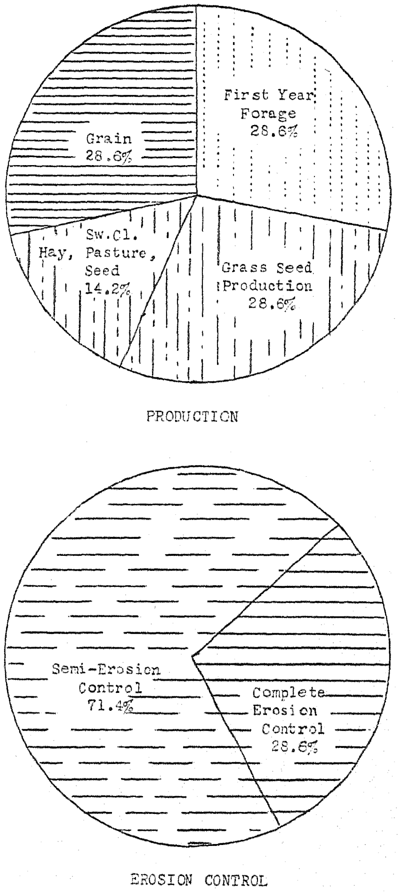

Fig. 8.—Soil-conserving rotations. Sweet clover 2 years, grass 3 years; and grain 2 years.

productivity. Erosion control obtained by the use of this rotation consists of two years of complete control and seven years of semi-erosion control in every nine-year cycle. The two years of complete control are made up of the first two years during which a grass cover is on the land. The seven years of semi-erosion control consist of one year of fall-plowed grass, two years of sweet clover, and four years of properly utilized grain stubble. The amount of control is graphically illustrated in Fig. 9. This rotation provides for a well-balanced farm income. It includes the production of grain, pasture, hay, and forage seeds.

SUMMARY

Crop land makes up approximately 75% of all lands in the South Palouse project. The use of soil-improving and soil-conserving crop

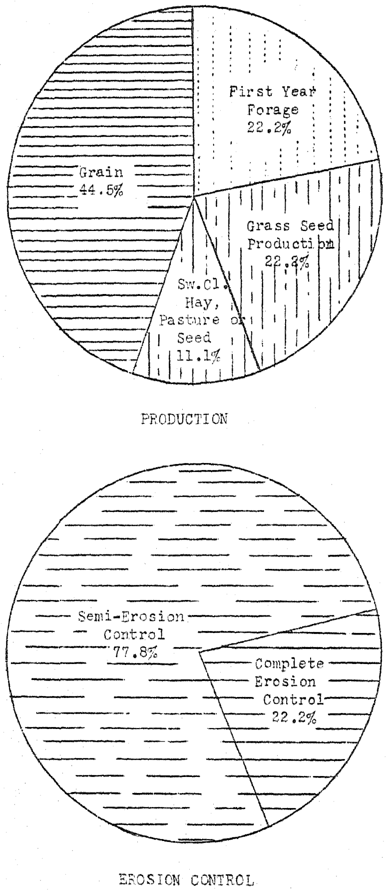

Fig. 9.—Soil-conserving rotations. Grass 3 years; grain 2 years; sweet clover 2 years, and grain 2 years.

rotations, combined with proper utilization of crop residues, are the most important measures of conserving soil and water.

The grain-fallow and the grain-pea soil-depleting cropping systems were in general use on most of the area until five years ago. In these systems the fields were unprotected from erosion during half of the critical erosion periods and had only semi-protection during the other half of the erosion periods in each two-year cycle.

Soil-improving rotations have been planned for crop lands having gently sloping and only moderately eroded soils. These rotations are designed to improve the physical condition of the soil and to increase or maintain the fertility and productiveness. They are as follows:

1. The six-year rotation (A) including two years of sweet clover, two years of grain, one year of fallow, and one year of grain produces a semi-erosion controlling cover on the land during five years out of every six. The sixth year in the cycle has no erosion control. This rotation is adapted to areas having moderate erosion potentials and not adapted to pea production.
2. The six-year rotation (B) including one year of sweet clover and peas and one year of grain has a semi-erosion controlling cover on the land four years out of every six, with the fifth and sixth years having no cover. This rotation is used only on the less eroded and gentler slopes on the farm.
3. The four-year rotation (C) including two years of sweet clover and grass and two years of grain produces a semi-erosion controlling cover on the land every year in the cycle. For this reason, it is used on more severely eroded and steeper crop land areas than either rotations A or B.

Soil-conserving rotations, have been planned for use on the most severely eroded crop lands and on the steeper slopes. In these rotations the land has an erosion-controlling cover on it a major portion of the

years in every cycle. For this reason, these rotations not only improve the productivity and physical condition of the soil, but also provide protective vegetative cover. They are as follows:

1. The six-year rotation (A) including alfalfa and grass four years and grain two years ties in very closely with the six-year rotation including sweet clover as a soil-improving crop. In this rotation the fields have complete erosion control three years out of every six. The other three years they have semi-erosion control.
2. The six-year rotation (B) including alfalfa and grass three years and grain three years is slightly less stringent in erosion control than rotation A. Complete erosion control exists on the land two years in every six, the other years being in a semi-erosion controlling condition. The six-year rotation including grass three years and grain three years has the same erosion controlling properties. The grass in this rotation is most commonly utilized for seed production. This type of rotation is used only on the more fertile areas where the physical condition of the soil is in need of improvement, rather than improvement of fertility.
3. The seven-year rotation (C), including sweet clover two years, grass three years, and grain two years, places more emphasis on income from grass seed than from grain. Erosion is completely controlled three out of every seven years. The remainder of the time is a semi-erosion controlling condition.
4. The nine-year rotation (D), including grass three years, grain two years, sweet clover two years, and grain two years, is designed to improve the soil fertility and productivity in addition to the other advantages of rotation B. In this rotation the land has complete erosion control on it two years in nine, the other seven years being in semi-erosion controlling condition.

Soil conserving and soil-improving crop rotations balance farm income by diversification of sources.

LITERATURE CITED

1. Hafenrichter, A. L., and Rockie, W. A. Ecological aspects of soil erosion in the Pacific Northwest as determined by the reconnaissance erosion survey. Northwest Science, 11:No. 4. 1937.
2. McGrew, P. C., and Horner, G. M. Soil and water conservation investigations. Pacific Northwest Soil Conservation Exp. Sta., Pullman, Wash. Progress Rpt., 1931–35.
3. Rockie, W. A. Snowdrifts and the Palouse topography. Geograph. Rev., 24: No. 3. 1934.
4. ————. Some important effects of the summer fallow system of farming on soil erosion in the Pacific Northwest. Northwest Science, 7:No. 1. 1933.
5. Schafer, E. G., Wheeting, L. C., and Vandecaveye, S. C. Crop rotations. Wash. Agr. Exp. Sta. Bul. 344:1–74. 1937.
6. Severence, George, Hunter, Byron, and Eke, Paul. Farming systems for eastern Washington and northern Idaho. (Idaho Agricultural Experiment Station, Washington Agricultural Experiment Station, and Bureau of Agricultural Economics U. S. Dept. Agr. in cooperation.) Idaho Agr. Exp. Sta. Bul. 173:1–83, 1930; and Wash. Agr. Exp. Sta. Bul. 244:1–83. 1930.
7. Vogel, Harold A., and Johnson, Neil W. Types of farming in Idaho. Part I, Agricultural Resources and Factors Affecting Their Use. Idaho Agr. Exp. Sta. Bul. 207:1–60. 1934.
8. Willard, Rex E., and Johnson, Neil W. Present Land Uses—Washington, Types of Farming Series, Part 1. Wash. Agr. Exp. Sta. Bul. 288:1–40. 1933.

THE INFLUENCE OF SPACE AND ARRANGEMENT ON THE PRODUCTION OF SOYBEAN PLANTS[1]

R. G. WIGGANS[2]

THE soybean, like any other crop which is being produced in its border area of adaptation, presents many special problems, the answers to which must be sought in the area where the production of the crop is being attempted. This paper is the report of a study of the effect of space and arrangement of plants on the production of soybeans in the northeastern range of their production. This is only one of many problems which might be studied with interest and profit. Further information is needed on varieties, inoculation, fertilization, cultivation, the effect of length of day, and utilization.

Accepting the recommendations of the corn belt investigators as to the best method of distribution of the seed of soybeans for maximum production, cultivated rows 36 inches apart were used in the beginning as a standard method in the experimental work at the New York State College of Agriculture. By 1930 the width of row had been reduced to 28 inches, to the advantage of increased production. A solid drill varietal test was established in 1931 to include the more promising varieties for grain. Both cultivated rows, 28 inches apart, and solid drills, with rows 8 inches apart, have been used in varietal trials continuously since that date. Table 1 gives the results in bushels per acre for three of the several strains in these tests.

TABLE 1.—*Comparison between cultivated rows and solid drilling of soybeans.*

Year	Yield in bushels per acre								
	Cayuga			Seneca			65344		
	28 in. rows	8 in. rows	Difference	28 in. rows	8 in. rows	Difference	28 in. rows	8 in. rows	Difference
1931	26.8	38.6	11.8	—	—	—	30.9	40.7	9.8
1932	25.0	37.4	12.4	28.0	38.2	10.2	24.0	36.1	12.1
1933	26.5	38.3	11.8	42.2	45.2	3.0	29.5	41.6	12.1
1934	30.4	31.9	1.5	39.9	42.0	2.1	32.8	37.5	4.7
1935	33.3	34.9	1.6	38.4	33.8	−4.6	30.9	32.4	1.5
1936	24.5	25.3	0.8	33.5	32.6	−0.9	26.4	28.4	2.0
1937	28.7	37.0	8.3	37.2	36.3	−0.9	30.6	36.1	5.5
Average			6.9			1.5			6.8

These results illustrate the advantage of the solid drill method over rows wider apart when early-maturing soybean varieties are used for the purpose of grain production. In only 3 out of 20 trials included in the table were the yields in the 28-inch cultivated rows as large as those in 8-inch solid drills. These three instances all occurred with

[1]Paper No. 225, Department of Plant Breeding, Cornell University, Ithaca, New York. Also presented at the annual meeting of the Society held in Washington, November 16, 1938. Received for publication December 27, 1938.

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one strain, which happens to be the largest of the three, and during years when some lodging occurred in the solid plantings. The average difference between the two methods of planting for the three varieties was 18.5% for the period. Although not entirely comparable, a fact which prevents the formulation of definite conclusions, these data are highly indicative. The yields taken from separate varietal trials are not exactly comparable. The trials, however, were in close proximity, often directly adjoining on the same type of land which had received the same treatment.

The above results, together with those from other varieties tested during 1931–33, stimulated the present method study. The study involves the influence of space and arrangement on the production of Cayuga soybeans, a new and recently introduced variety in the New York area.

PLAN OF THE EXPERIMENT

The detailed plan used throughout the four years during which this experiment was continued is given in Table 2. The spacing within the rows varied from ½ inch to 6 inches, the distance between rows from 8 inches to 32 inches, while the number of plants per square foot varied from 1 to 18. One plant per square foot is approximately equivalent to a seeding rate of 1 peck per acre for Cayuga soybeans. During the first year, rows with widths of 20 inches, 28 inches, and 36 inches were included as well as a 9-inch spacing in the rows, but these were discontinued in later years as unnecessary for the purposes of the experiment. The question may arise as to why widths of 7, 14, 21, and 28 inches were not chosen instead of those which were used since such widths would lend themselves to the use of the ordinary grain drill. Experience has shown that an 8-inch row is about as narrow as can be conveniently employed where the work must be done by hand labor; further, the experimental equipment available was arranged for the widths as used; and, finally, it was thought that interpolation might be used with a fair degree of accuracy in estimating the yields for any desired width not included.

TABLE 2.—*Plan of experiment to determine the spacing for optimum yields of Cayuga soybeans.*

Distance between plants in the row, inches	Number of plants per sq. ft. for different distances between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
½	—	—	18	12	9
1 or 1⅛*	18	12	9	6	4
1⅓ or 1½*	12	9	6	4	3
2 or 2¼*	9	6	4	3	2
3	6	4	3	2	1½
4 or 4½*	4	3	2	1½	1
6	3	2	1½	1	—

*These differences in spacing are made necessary in order to get the desired number of plants per unit area.

All plantings were made by hand in four-row blocks 20 feet long. Only the two central rows were harvested for this study since the wide variation in rate and spacing offered a maximum opportunity for competition, a factor of considerable importance in such an experiment. Each planting was repeated eight times. The

seed was specially graded, thoroughly mixed, and hand picked, and was of high germination. All seeds were counted, due consideration given to germination, and a 5% allowance made for field losses. Hand cultivation was practiced to eliminate weeds as a factor. Individual rows were handled as units during harvesting, threshing, weighing, and preliminary calculation of data, and finally, the two central rows were combined and considered as a unit. The experiment was always conducted on as uniform an area as possible which had been prepared as long ahead of planting as convenient and kept free of weeds by harrowing occasionally. The fertilizer was applied uniformly over the entire experimental plat with a grain and fertilizer drill, previous to the final preparation of the soil.

EXPERIMENTAL RESULTS

The yield of soybeans is affected materially by the spacing of the plants. Not only is the yield influenced by the distribution of the plants within the rows, but also by the distance between rows.

YIELDS FROM 1934–37

The data in Table 3 show the yields in bushels per acre for the four years during which this test was conducted. The construction of the table follows exactly the plan of the experiment as given in Table 2. Each individual yield in the table represents the average of eight repetitions, each replicate being the average of the two central rows of a four-row block.

The probable errors of the seasonal yields are extremely low for the first three years of the experiment and for the thicker plantings in 1937. The variation between repetitions in the thinner rates of planting in 1937 were much larger than in previous years, and were much the largest in the experiment. A difference between yields of 2.5 bushels per acre would be statistically significant in a very large percentage of the comparisons. The higher differential necessary in the thinner plantings in 1937 is due to the irregular stand resulting from unfavorable conditions immediately following the seeding operations. Heavy rains on a well-prepared clay soil resulted in a poor stand in some cases where the seeds were far apart. Under such conditions the individual seedlings were unable to break through, whereas thicker plantings resulted in good stands by virtue of the combined efforts of the many seedlings being able to break the crust. A set of adverse conditions such as existed in 1937 was thought necessary in this experiment in order to avoid erroneous conclusions, since such conditions occur more or less frequently and cannot be avoided.

A detailed study of this table shows extremely uniform relationships for the several years with the exceptions cited above. There are a few individual variations from year to year.

FOUR YEARS AVERAGE PRODUCTION

As summarized in the upper half of Table 4, the relationship between the various factors under study becomes clearer and all but one of the exceptions disappear. The ½-inch spacing in the 24-inch rows shows a smaller yield than the next thinner rate, a difference statistically insignificant.

TABLE 3.—*Effect of the distance between rows and the distance between plants in the row on the yield in bushels per acre of Cayuga soybeans, 1934 to 1937.*

Distance between plants in the row, inches	Distance between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
			1934		
½	—	—	32.9	32.4	29.8
1 or 1⅛	36.6	34.6	34.0	32.2	30.2
1⅓ or 1½	38.9	34.7	33.5	30.7	28.6
2 or 2¼	36.0	35.0	32.9	32.0	28.6
3	37.9	33.9	33.0	30.6	29.0
4 or 4½	37.4	34.6	33.3	30.9	27.4
6	37.2	32.1	31.1	29.2	—
			1935		
½	—	—	39.2	35.2	33.8
1 or 1⅛	42.8	38.5	40.0	36.8	32.9
1⅓ or 1½	43.1	39.7	37.4	36.5	31.2
2 or 2¼	44.8	38.3	37.7	34.2	28.1
3	41.3	38.2	36.0	29.9	26.8
4 or 4½	38.0	38.1	32.3	28.9	22.5
6	39.8	28.9	29.3	21.9	—
			1936		
½	—	—	32.9	31.8	28.4
1 or 1⅛	36.1	35.0	32.1	32.7	28.7
1⅓ or 1½	33.8	34.7	34.4	31.6	28.9
2 or 2¼	35.8	33.0	33.5	31.3	27.5
3	35.3	34.1	33.7	29.4	26.3
4 or 4½	33.2	32.6	30.8	28.7	25.4
6	34.7	33.8	30.7	26.4	—
			1937		
½	—	—	41.3	37.3	35.9
1 or 1⅛	44.9	39.8	39.7	38.0	32.6
1⅓ or 1½	44.4	39.0	37.4	36.2	29.9
2 or 2¼	42.7	39.8	32.9	32.4	23.0
3	43.8	35.5	32.8	26.7	21.8
4 or 4½	35.8	29.0	21.2	15.1	8.3
6	29.5	18.2	17.0	13.0	—

The data in this table show four points of special interest, (1) that yield decreases with any and all increases in the distance between rows; (2) that a wide range in the distance between plants in the row has little effect on the production, although there is always a tendency, with the exception cited above, for the yield to be greatest with the thickest planting, with a gradual falling off as the spacing increases; (3) that spacings greater than 3 inches within the row show significantly smaller yields than the thicker rates; and (4) that a yield of 40 bushels approaches the "ceiling" for this particular variety under the soil and climatic conditions existing in central New York.

The average of all the yields of the several spacings within the rows for the various widths of rows is shown in Fig. 1, by the solid line. The maximum yields for the several row widths are illustrated by the broken line at the top of the figure. Both these graphs show conclu-

sively that the yield decreases as the width of row increases. The same things might be shown with graphs made either from the yields of a given spacing within the rows of the various widths of rows or by the same total rate of seeding per acre where the spacing within the row is narrowed in proportion to the increase in the distance between rows.

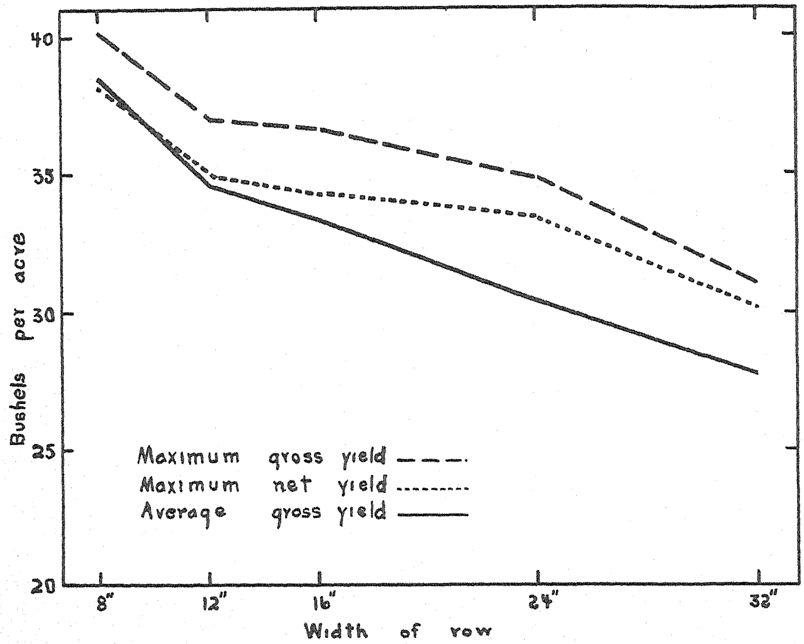

Fig. 1.—Showing the effect of the width of rows on the four-year average yield of Cayuga soybeans.

FOUR YEARS AVERAGE NET PRODUCTION

The total or gross yield of soybeans in an experiment of this kind is not the final measure. When wide differences in the rate of seeding are employed, the amount of seed used becomes a factor of considerable importance. In the lower half of Table 4 the net yields are given, which represent the total or gross production less the seed sown. Such a treatment of the data changes the picture to a considerable extent. The differences may be indicated as follows: (1) That the thickest plantings within the rows do not give the greatest returns, and (2) that the spacing within the rows giving the maximum yield varies with the width of row. This varies from 3 inches apart in the 8-inch rows to 1 inch apart in the 32-inch rows.

The maximum net yields for the various row widths is shown by the fine dotted line in Fig. 1. It will be noted that each of the three curves in this figure have the same general shape, showing the decline in yield with the widening of the rows. From these data it would seem reasonable to expect yields of rows with intermediate widths not

included in the experiments to fit closely into the curves as given in the figure.

EFFECT OF NUMBER OF PLANTS PER SQUARE FOOT OF AREA

The effect of the number of plants per square foot of area occupied is clearly shown in Table 5. The upper portion shows the gross and the

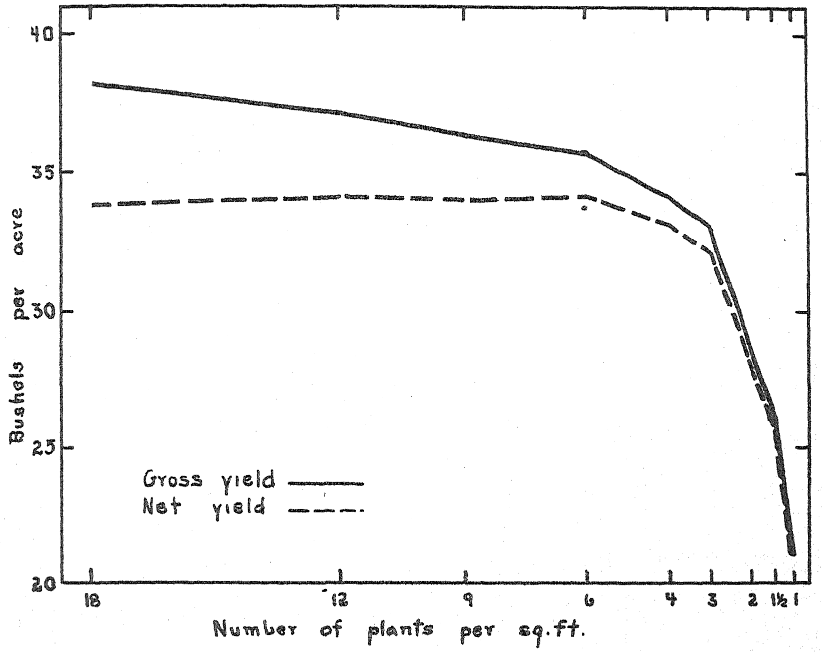

Fig. 2.—Showing the effect of the number of plants per square foot on the four-year average yield of Cayuga soybeans.

lower portion the net production. The maximum yields for the several row widths are indicated by asterisks. The average of the several arrangements of plants with a given number per square foot is shown graphically in Fig. 2, where the solid line represents gross and the broken line the net production. It is in the graph that the effect of the space given individual plants is best illustrated. There is a gradual falling off of gross yields from 18 to 6 plants per square foot, a much more rapid decline from 6 to 3 plants per square foot, and a precipitous drop from 3 plants to 1 plant per square foot.

The net yield curve is decidedly different from the total or gross yield curve in that it not only shows a close approximation to a straight line curve but also a level curve from 18 to 6 plants per square foot. The curve from 6 plants to 1 plant per square foot is very similar to the curve for the total yield. The net results show no purpose in seeding at a rate beyond one which will give 6 plants per square foot, regardless of the method of distribution, except for compensation for possible losses in cultivation.

TABLE 4.—*Effect of the distance between rows and the distance between plants in the row on the yield in bushels per acre of Cayuga soybeans for a 4-year average.*

Distance between plants in the row, inches	Distance between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
Total or Gross Yield					
½	—	—	36.6 (*18*)*	34.2 (*12*)*	32.0 (*9*)*
1 or 1⅛	40.1 (*18*)*	37.0 (*12*)*	36.5 (*9*)	34.9 (*6*)	31.1 (*4*)
1⅓ or 1½	40.1 (*12*)	37.0 (*9*)	35.7 (*6*)	33.8 (*4*)	29.7 (*3*)
2 or 2¼	39.8 (*9*)	36.5 (*6*)	34.3 (*4*)	32.5 (*3*)	26.8 (*2*)
3	39.6 (*6*)	35.4 (*4*)	33.9 (*3*)	29.2 (*2*)	26.0 (*1½*)
4 or 4½	36.1 (*4*)	33.6 (*3*)	29.4 (*2*)	25.9 (*1½*)	20.9 (*1*)
6	35.3 (*3*)	28.3 (*2*)	27.0 (*1½*)	22.6 (*1*)	—
Net Yield (Total Production Less Seed Sown)					
½	—	—	32.1 (*18*)	31.2 (*12*)	29.7 (*9*)
1 or 1⅛	35.6 (*18*)	34.0 (*12*)	34.2 (*9*)	33.4 (*6*)	30.1 (*4*)
1⅓ or 1½	37.1 (*12*)	34.7 (*9*)	34.2 (*6*)	32.8 (*4*)	28.9 (*3*)
2 or 2¼	37.5 (*9*)	35.0 (*6*)	33.3 (*4*)	31.7 (*3*)	26.3 (*2*)
3	38.1 (*6*)	34.4 (*4*)	33.1 (*3*)	28.7 (*2*)	25.6 (*1½*)
4 or 4½	35.1 (*4*)	32.8 (*3*)	28.9 (*2*)	25.4 (*1½*)	20.6 (*1*)
6	34.5 (*3*)	27.8 (*2*)	26.4 (*1½*)	22.3 (*1*)	—

*Number plants per square foot indicated by figures in parenthesis.

TABLE 5.—*Effect of the number of plants per square foot on the yield in bushels per acre of Cayuga soybeans for an average of four years.*

Plants per square foot	Distance between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
Total or Gross Yield					
18	40.1*	—	36.6*	—	—
12	40.1*	37.0*	—	34.2	—
9	39.8	37.0*	36.5	—	32.0*
6	39.6	36.5	35.7	34.9*	31.3
4	36.1	35.4	34.3	33.8	31.1
3	35.3	33.6	33.9	32.5	29.7
2	—	28.3	29.4	29.2	26.8
1½	—	—	27.0	25.9	26.0
1	—	—	—	22.6	20.9
Net Yield					
18	35.6	—	32.1	—	—
12	37.1	34.0	—	31.2	—
9	37.5	34.7	34.2*	—	29.7
6	38.1*	35.0*	34.2*	33.4*	29.8
4	35.1	34.4	33.3	32.8	30.1*
3	34.5	32.8	33.1	31.7	28.9
2	—	27.8	28.9	28.7	26.3
1½	—	—	26.6	25.5	25.6
1	—	—	—	22.3	20.6

*Maximum yields.

CONCLUSIONS

The results for four years of varying rates of seeding of Cayuga soybeans as influenced both by the spacing within the row and the width between the rows lead to the following general conclusions. The specific conclusions directly applicable to early-maturing soybean varieties as represented by Cayuga were presented above as the experimental results were discussed.

1. The nearer the arrangement of plants on a given area approaches a uniform distribution, the greater will be the yield. Other things being equal, the narrower the distance between rows until the distance between rows equals the space between plants in the row, the greater the yield.
2. Within wide ranges the number of plants per square foot of area has little effect on net increases. There is nothing to be gained by seeding beyond a given optimum.
3. The soybean plant, like many others, has the ability to make wide adjustments to space.
4. Optimum rates and spacings for soybeans should be determined not only for the various soybean-producing areas but also for the varieties to be grown. Large-growing, late-maturing varieties would hardly be expected to require the same rate or spacing for optimum yields that small-growing, early-maturing varieties require.
5. A variety of soybeans has an optimum number of plants per unit area for the maximum net increase. For Cayuga this rate is 6 plants per square foot.

SOME FACTORS AFFECTING THE PREVALENCE OF WHITE CLOVER IN GRASSLAND[1]

B. A. Brown[2]

WHITE clover (*Trifolium repens*) is the most important legume found in the permanent grassland of the northeastern United States. As shown by several investigators (1, 4, 5, 7, 9, 10),[3] grassland with a considerable proportion of its area occupied by white clover yields much more than grass alone, and frequently as much or more than can be stimulated by the addition of large amounts of nitrogenous fertilizers. Not only are total yields greatly enhanced, but the palatability, nutritive value, and the seasonal distribution of the pasturage are improved by white clover. It is, therefore, of much economic importance that permanent grassland be managed so as to assure this legume a prominent place in the sward. It should be admitted, however, that in spite of the widespread interest in and amount of research with white clover, no one knows the reasons for the amazingly sudden changes in its prevalence.

During the nearly 20 years of pasture research at the Storrs, Conn., Agricultural Experiment Station, there have accumulated many data pertaining to factors affecting the prevalence of white clover. Although these results have not led to definite conclusions, it seems advisable to publish them at this time.

An important factor affecting the prevalence of white clover, but one on which the author has few data, is that of soil type. All of the experiments reported in this paper were conducted on Charlton fine sandy loam soil. This soil is well adapted for grasses and clovers if provided with the proper fertilizers.

Most of the lawn mowing in these experiments has been done with a roller driven type of power mower.

WHITE CLOVER AND YIELDS OF GRASSLAND

The importance of white clover to yields of grassland is indicated by the data in Table 1, which summarizes this Station's results on that subject when only volunteer clover is concerned.

Under either grazed or lawnmowed conditions, production was 5 to 10% higher with PKL than PKN fertilization when clover occupied 30% or more of the area. The reverse was true when the area with clover fell to 10% or less.

The effects of seeding Ladino or Kent[4] white clover on plats of nine grasses in pure culture and also of fertilizing these grasses with varying amounts of nitrogen are shown in Table 2. In this experiment, seeding Ladino clover resulted in more dry matter than adding nitro-

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station, Storrs, Conn. Also presented at the meeting of the American Society of Agronomy, Washington, D. C., November 16–18, 1938. Received for publication December 29, 1938.

[2]Associate Agronomist.

[3]Reference by number is to "Literature Cited", p. 332.

[4]Strain of white clover indigenous in old, closely grazed pastures of Kent County, England.

TABLE 1.—*Yields and prevalence of white clover.*

Period	Relative yields		Area occupied by clover, %†	
	PKL*	PKN*	PKL	PKN
	Cut with Lawnmower‡			
1932–35......	100	91	38	7
1936–37......	100	128	4	1
	Grazed§			
1924–28......	100	95	65	38
1932–37......	100	114	9	5

*P = superphosphate; K = muriate of potash; L = ground limestone; and N = nitrogenous fertilizers.
†Estimated from inspection.
‡Field D, treatment No. 30 vs. treatment No. 8 (averages of six plats).
§Cummings pasture, plat 8N vs. plats 9N and 9S.

gen at 84 pounds annually. The Kent clover plats outyielded the unfertilized ones by a wide margin, although the latter had large amounts (over 30%) of volunteer white clover, and also produced more pasturage than N1 fertilization.

TABLE 2.—*White clovers and yields of grassland.*

Treatment*	Dry matter per acre, lbs.†		
	1936	1937	Total
Kent clover seeded.......................	2,005	2,857	4,862
Ladino clover seeded.....................	3,481	3,493	6,974
No.......................................	1,584	2,626	4,210
N1.......................................	1,911	2,871	4,782
N12......................................	2,295	2,924	5,219
N123.....................................	2,707	3,170	5,877

*The clovers were seeded at 5 pounds in March, 1936, without tillage, on surface of plats of grasses planted in August, 1935. "N" equals nitrogen at 28 pounds from Calnitro. The figures after the letter N refer to time of application: No, none; N1, April; N12, April and June; and N123, April, June, and August. Thus, N123 means a total of 84 pounds in three applications.
†Average of nine grasses on R3 seeded in pure culture in August, 1935.

SOURCE OF SEED

Practically all of the white clover in the permanent pastures throughout the world has volunteered and is, of course, of unknown origin. Selection of individual plants from such habitats has demonstrated the presence of many widely varying types or strains. The predominating type is the one best adapted for the environment resulting from the management of any given pasture. There are, also, great variations in the climates of the regions where white clover seed is produced and this may influence its longevity, especially when planted in areas with more rigorous weather conditions.

Twelve strains of white clover[5] were planted in the spring of 1936 on 50- by 6-foot plats. In the spring of 1937, nine strains of white clover, including five not in the 1936 tests, were sown on triplicated,

[5]E. A. Hollowell of the U. S. Dept. of Agriculture kindly cooperated by furnishing seed of most of the white clover strains.

40- by 6-foot plats, located on another field. In the first case, the clovers were seeded at 18 pounds with commercial Kentucky bluegrass at 100 pounds per acre. In the second instance, the clovers were seeded at 2 pounds and Kentucky bluegrass at 24 pounds. In both cases, the plats were cut to 1 inch above the soil with a lawnmower when the vegetation reached a height of 3 to 4 inches.

The stands of these clovers are given in Tables 3 and 4. The data show a very strong tendency for the strains indigenous in old pastures of several countries to maintain better stands than the others. In this respect, the Danish, Polish, and commercial white Dutch clovers were among the poorest. The strains from several states of the United States were intermediate and, to date, there appear to be no significant differences between southern, northern, and far western sources. The commercial strains flowered much more profusely than any of the others. This suggests selection for seed bearing rather than for vegetative growth or longevity.

TABLE 3.—*Source of white clover seed and longevity.**

Source of seed†	Area occupied by clover, %‡			
	Oct., 1936	Oct., 1937	May, 1938	Aug., 1938
Denmark	50	2	5	5
Poland	95	5	10	15
Idaho	85	10	10	15
Denmark ("Morso")	70	6	10	15
New York, old pasture	80	10	15	20
Oregon	80	3	5	25
Missouri	65	10	15	20
England (Cotswold native)	60	35	25	30
New Zealand ("virgin")	90	30	20	40
England (E. Anglia native)	80	40	40	55
New Zealand (native)	80	25	30	60
England (Kent old pasture)	75	35	40	65

*Field R4; Seeded spring of 1936.
†"Native" refers to "wild" strains.
‡Estimated from inspection.

TABLE 4.—*Source of white clover seed and longevity.**

Source of seed†	Area occupied by clover Sept., 1938, %‡
Volunteer	7
Commercial white Dutch	8
Poland	15
Oregon	17
Wisconsin	21
Louisiana	25
Illinois	29
Mississippi	38
England (Kent old pasture)	45
New York (native)	57

*Field T; seeded spring of 1937 with Kentucky bluegrass.
†"Native" refers to "wild" strains.
‡Estimated from inspection.

CLIMATIC CONDITIONS

The marked prevalence of white clover in the so-called *clover* years has been ascribed by some writers to the weather. No doubt some climatic factors are important, but the clover readings since 1922 on the series of grazed pastures at Storrs, Conn., indicate that the weather has been over-emphasized. As may be noted in Table 5, remarkable increases in clover occurred on two occasions, many years apart, both during the two growing seasons immediately following the *first* application of P to pastures where the soil was very deficient in that element. Repeating the P at 3- to 5-year intervals has not maintained or brought back the clover to the high levels obtained soon after the initial applications. The competition of the grasses, greatly thickened and invigorated by fertilizers and association with clover, appears to be much more potent than any weather factor experienced in this locality. This supposition is supported by results presented below.

TABLE 5.—*The relative effects of climate and fertilization on the prevalence of white clover.**

Year	Area occupied by white clover, %†		Area occupied by grasses, %†	
	First P in 1924	First P in 1932	First P in 1924	First P in 1932
1922.........	9	10	—	—
1925.........	63	9	—	—
1932.........	11	1	71	47
1933.........	10	70	—	—
1936.........	7	40	—	—
1937.........	6	10	74	74
1938.........	21	17	54	67

*Cummings pasture grazing experiment; plats 1N and 8N vs. 3W. All of these plats also received limestone and 8N and 3W also received potash.
†Estimated from inspection.

SPECIES OF GRASSES

During the early spring of 1936, six treatments were initiated on duplicate 8- by 50-foot plats on each of nine common grasses seeded in pure culture the previous August. The nine grasses in this experiment were: Kentucky bluegrass (*Poa pratensis*), Canada bluegrass (*Poa compressa*), Rhode Island bent (*Agrostis tenuis*), timothy (*Phleum pratense*), orchard (*Dactylis glomerata*), perennial rye (*Lolium perenne*), smooth brome (*Bromus inermis*), meadow fescue (*Festuca pratensis*), and tall oat (*Arrhenatherum elatius*). The six treatments were Kent white clover seeded; Ladino clover seeded; and No, N1, N12, and N123 fertilization (see Table 2 for explanations of symbols). The clovers were sown at the rate of 5 pounds in March on the surface without tillage. Calnitro was the source of nitrogen. The soil had a pH of 5.6 and was well supplied with P and K.

Since about May 1, 1936, the vegetation has been harvested when about 4 inches high with a motor lawnmower, set to cut to 1 inch above the soil. From 6 to 11 cuttings have been made each year. All clippings have been removed from the plats.

The Kent and Ladino clovers had excellent stands by midsummer of the year of seeding (1936). During the last part of the 1936 season and most of the 1937 season, Ladino clover grew so thickly and rapidly that a casual inspection would not have revealed the presence of the grasses. Native clover soon volunteered and under the No treatment occupied nearly as much area as Ladino and Kent clovers did on their respective plats. Estimates of the area in clover have been made for each plat twice each season. For the purpose of showing in a brief form the marked effects of type of grass on the prevalence of white clovers, the nine grasses have been divided into three groups, as follows: (a) The bluegrasses and bent grasses which maintain good stands when cut with a lawnmower; (b) timothy, orchard, and perennial rye grasses, which had poor to fair stands during the three years in question; (c) brome, meadow fescue, and tall oat grasses, which had very poor stands soon after starting the lawnmowing. The average stands of clover in 1937 and 1938 for these three groups of grasses are shown in Table 6.

TABLE 6.—*Effects of species of grasses and nitrogenous fertilizers on the prevalence of white clover.**

Treatment†	Area occupied by white clover, %‡		
	With Kentucky bluegrass, Canada bluegrass and bent	With orchard, perennial rye, and timothy	With tall oat, brome, and meadow fescue
Kent seeded	41	51	75
Ladino seeded	33	45	59
No	35	50	67
N1	23	41	68
N12	17	37	65
N123	13	29	62
Average	27	42	66

*The values in this table are the averages of clover stands for two readings for each grass on R3 in both 1937 and 1938.

†No means no N; N1, April N; N12, April and June N; and N123, April, June, and August N. Each application supplied N at 28 pounds, all from Calnitro.

‡Estimated from inspection.

From a study of Table 6, it is readily apparent that the competition afforded by the different types of grasses had very marked effects on the prevalence of the clovers. This is true regardless of seeding or application of N. It is obvious that the degree of retardation of clover by N depends on the amounts of the accompanying grasses present to utilize the N. For example, with no N there was about half as much clover with the bluegrass-bent group as with the brome-tall oat-fescue group of grasses, but under N123 fertilization the corresponding value was one-fifth.

Blackman (2) found that ammoniacal N appeared to have a toxic effect on white clover. In the Storrs experiment, Calnitro was the source of N. About one-half of the N in Calnitro is in the ammoniacal form, yet in the case of grasses with very poor stands, applying that fertilizer at 140 pounds per acre three times each season for 3 years has decreased the clover only from 67 to 62%. These results strongly

indicate that the indirect effects of N, by increasing the competition of grasses, are far more important than any direct effects. Of course, salts like $(NH_4)_2SO_4$, which have a strong acidifying effect on the soil, may in a short time change an already acid medium to a reaction entirely unsuitable for clover. Some unpublished data show that this is especially true of surface applications.

Further evidence regarding the important effects of kind of grass on the prevalence of white clover is furnished by another experiment in which Ladino and Kent clovers were seeded at 2 pounds in triplicated 40- by 6-foot plats with each of several grasses. Harvesting has been similar to that in the experiment discussed above. At the end of the second season, there was three times as much Ladino and twice as much Kent clover with perennial rye as with Rhode Island bent grass (Table 7).

TABLE 7.—*Effects of different grasses on prevalence of white clover.**

Species of grasses seeded	Area occupied by clover, %†	
	Ladino seeded	Kent seeded
Rhode Island bent	21	28
Kentucky bluegrass	33	45
Kentucky bluegrass and Rhode Island bent	23	41
Kentucky bluegrass and timothy	38	25
Orchard	46	37
Orchard and timothy	57	40
Timothy	72	45
Meadow fescue	72	50
Perennial rye	72	55

*Field T; seeded spring 1937; clover readings of Sept., 1938.
†Estimated from inspection.

SOIL FERTILITY AND FERTILIZATION

In northeastern United States, one of the first visible effects of mineral fertilizers on run-down pastures has been the pronounced spread of native white clover. Later the better grasses usually have become dominant and this has been accompanied by a marked reduction in clover. It is important to learn which, if any, methods of fertilizing will maintain a large (over 30% of the area) amount of clover in the turf. The Storrs Experiment Station has two experiments which furnish some evidence on this point. One is the grazing project with 17 2-acre pastures; the other is contiguous to the first and contains over 100 duplicate 50- by 20-foot plats on a long untilled meadow cut in June for hay and grazed during the late summer and fall.

In both cases, the untreated soil is acid (pH 5.2) and very deficient in easily soluble P. The fertilizers have been applied on the surface and there has been no seeding or tilling for 25 years at least.

The more recent estimates of native white clover in the grazed pastures are given in Table 8. It is now 14 years since the first fertilizers were applied to those pastures and 6 years since any changes were made in the schedule. Since 1928, rotational heavy grazing with yearling steers or heifers, receiving no supplemental feed, has been

the practice. Therefore, the values in Table 8 represent the response of white clover to long-continued, exact treatments under actual grazing conditions.

TABLE 8.—*Fertilization of grazed pastures and the prevalence of white clover.*

General treatment*	Area occupied by white clover			
	Oct., 1937	June, 1938	Sept., 1938	Average
No P	1	1	3	2
P	3	5	10	6
PL	9	14	21	15
PLK	9	17	26	17
PK	6	13	11	10
PKN1 or N2 or N3	4	7	11	7
PLKNN1	2	—	10	6
PLKN12 or N23	4	—	14	9
PLKN123	2	1	11	5

*P = superphosphate to supply P_2O_5 at 400 pounds per acre from 1924 to 1938; K = muriate of potash to supply K_2O at 250 pounds per acre from 1924 to 1938; L = limestone at 4,000 pounds per acre from 1924 to 1938; N = nitrogen at 28 pounds per acre at each application, and NN = nitrogen at 56 pounds per acre at each application. The numbers after the letters N or NN refer to time of application of nitrogen. 1 means April; 2, June; and 3, August applications. N123 means a total of 84 pounds in three applications. The nitrogen was supplied by a mixture of 200 pounds of sulfate of ammonia and 100 pounds of nitrate of soda through 1934 and since then entirely by Calnitro.

It is readily apparent that without the addition of P there was very little clover. There have been appreciable proportions of clover with superphosphate alone, but over twice as much when limestone was included with the superphosphate. Potash, either with superphosphate or superphosphate and limestone, has made clover somewhat more prominent, the complete minerals (PLK) resulting in the most clover.

Nitrogen, supplied since 1935 in the neutral carrier, Calnitro, has kept the percentages of clover very low until 1938, when, in common with most of these pastures, one of those marked inexplicable increases occurred between June and September. As most of the grass population is composed of the turf-forming species, Kentucky bluegrass and Rhode Island bent, and in view of the data, presented in previous pages, showing how effective these grasses are in reducing white clover in mixed stands, it is concluded that the effects of the N have been chiefly indirect, that is, in increasing the competition of the grasses.

The second experiment to be considered here was started in 1930 on a meadow run out by the long removal of hay without any fertilization. For the sake of brevity, only the averages of clover readings for groups of treatments, such as several N or P carriers or time of adding fertilizers, are given in Table 9.

It is evident that on this field P or L alone or together have not been very influential in promoting the advent of clover. In contrast to the nearby grazing experiment, the addition of potash, with either P or PL, has resulted in a very pronounced increase in clover. Probably the great response to potash here was due to the long-continued removal of hay, *viz.*, run out by mowing rather than by grazing. Where potash was applied in April 1937 for the first time, even larger

TABLE 9.—*Fertilization of hay land and prevalence of white clover.**

Fertilization†	Area occupied by white clover, %‡			
	June, 1936	Sept., 1937	May, 1938	Average
L	4	4	1	3
P	8	4	4	5
PK	12	18	17	16
LP	4	4	5	4
LPK	12	25	23	20
LPK (First K in 1937)	7	40	37	28
LPKN	12	20	21	18
LM	21	22	21	21
LMP	37	30	39	35
All L plats	13	21	20	18
All LP plats	14	23	22	20
All LPK plats	12	24	22	19
All M plats	29	26	30	28

*This land has been mowed for hay in June and grazed periodically in late summer and fall.
†L = limestone at 4,000 or more pounds per acre since 1930; P = phosphorus carriers to supply at least 300 pounds per acre of P_2O_5 since 1930; K = muriate of potash to supply at least 200 pounds per acre of K_2O since 1930; N = nitrogen carriers to supply at least 30 pounds per acre of N annually since 1930; and M = manure at 5 tons per acre annually, or 10 tons biennially, since 1930.
‡The results of several treatments, differing only in N or P carrier or time of application, have been grouped in this table. Areas estimated from inspection.

amounts of clover were present in September 1937 and May 1938. Again this is considered due to the thinner stand of grasses where little clover had grown previous to 1937.

The average results of several carriers and times of application of N show little reduction in clover from the N. However, some of the N plats, particularly those receiving a large amount at one time in either April or June, have had very rank grass and little clover.

The most clover has occurred on the plats fertilized with limestone, superphosphate, and manure. The reasons for the very beneficial effects of manure have not been determined, although carriers of many minor elements have been added to other plats of clover to learn if one or more might be of value. In this case, manure may owe its superiority to the additional potash supplied by 5 tons each year. On a similar soil, this has been found to be true of alfalfa.

MANAGEMENT

Some investigators have found the date, frequency, and closeness of grazing or mowing to be very influential on the prevalence of white clover (6, 7, 8). Very close and frequent grazing or mowing, especially during May and June, when grasses make their most rapid growth in the north temperate zone have favored certain types of white clover. It was under such conditions that the Kent old pasture strain of clover developed in the Romney Marsh district of England. Management to promote large proportions of white clover in pastures usually favors the extremely low-growing types which are not entirely defoliated by close grazing. That this kind of management is not always necessary for *all* types is shown by the large amounts of vol-

unteer, native white clover maintained for several years on the series of hay plats discussed in the preceding section of this paper.

At the Storrs Experiment Station, the Ladino variety of white clover has maintained much better stands under more lenient systems of cutting. For example, it has been almost entirely eradicated from some Kentucky bluegrass-Ladino clover plats by two seasons of lawnmowing (cut *when* 3 or 4 inches *to* 1 inch), but has spread into and now constitutes nearly 100% of the stand on adjacent hay land where there had been no seeding of Ladino. Several experiment stations have found Ladino to be much more productive than other varieties of white clover. It is of considerable importance, therefore, to learn the best methods of managing land seeded with this legume. Although far from complete, the experiments at Storrs, where Ladino has been cut by lawnmowers and mowing machines and also grazed in different ways, indicate that an average of about one cutting or grazing per month and not shorter than 2 inches above the soil will give the best results over a period of 3 years or more.

One season's cutting of Ladino to ½ inch reduced its stand appreciably. This was true also of Kent clover when seeded with Kentucky bluegrass. In the case of the Cornell 1937 seed mixture, the ½ inch cutting did not decrease the amount of clover, probably because less Kentucky bluegrass, a very competitive turf-forming species, was seeded in that mixture. These data are summarized in Table 10.

TABLE 10.—*Effects of cutting white clovers to different heights.**

Mixture seeded	Area occupied by clover, Sept. 1938, %†	
	Cut to 1 inch	Cut to 0.5 inch
Cornell 1937	43	50
Kentucky bluegrass and Ladino	33	20
Kentucky bluegrass and Kent	45	23

*Field T; seeded spring of 1937, but only subjected to different cuttings in 1938. Cut when 4 inches high.
†Estimated from inspection.

The average amounts of volunteer native white clover found in 1934 and 1935 in Kentucky bluegrass and Rhode Island bent grass plats under four different fertilizer treatments and four frequencies of cutting since 1932 are given in Table 11. The soil had a reaction of pH 6.0 and was well supplied with P and K. Under those conditions, there was a tendency in all cases for the clover to increase with less frequent mowing. Regardless of height when cut, the N123 fertilization reduced very markedly the amounts of clover.

In concluding this section on management of experimental plats, the writer takes the opportunity to express again the opinion that standardization in methods of performing certain experimental work may defeat the very purpose of the experiment. This danger arises because any given culture may or may not give its best or even a mediocre response under any specific practice. Thus, using the same management for evaluating the worth of all species and varieties of grasses or legumes might be likened to deciding on all men's fitness for all kinds of work by their knowledge of a single subject.

TABLE 11.—*Frequency of cutting Kentucky bluegrass and Rhode Island bent grass plats and prevalence of volunteer native white clover.*

Fertilization*	Percentage of area occupied by white clover,† plats lawnmown when vegetation reached height of			
	2 in.	3 in.	4 in.	5 in.
No	21	23	29	34
N1	21	20	26	26
N12	17	16	18	21
N123	7	5	7	13
Averages	17	16	20	24

*No = no nitrogen; N1 = nitrogen at 28 pounds in April; N12 = nitrogen at 28 pounds in April and June; and N123 = nitrogen at 28 pounds in April, June, and August. The nitrogen was from a mixture of 200 pounds of sulfate of ammonia and 100 pounds of nitrate of soda.
†Estimated from inspection.

SUMMARY

The causes of the wide fluctuations in the prevalence of white clover (*T. repens*) in grassland are still largely undetermined. The results at many experiment stations have shown the importance of having large percentages of white clover in permanent grasslands. These findings are supported by results at the Storrs, Conn., Agricultural Experiment Station.

Over a 3-year period, strains of clover, indigenous in old pastures of England, New Zealand, and the United States, have maintained the best stands in grass-clover seedings. Polish, Danish, and commercial white Dutch were the shortest lived of 18 strains. In respect to longevity, there appeared to be little choice between seed from northern, southern, or far western parts of the United States.

Climatic conditions have been of less importance than fertilization or species of grasses in the maintenance of white clover in mixed stands.

Clover has been much less prevalent with the turf-forming grasses, such as the bluegrasses and bents, than with species having more open stands.

The retarding effects of nitrogenous fertilizers on clover in grassland were due chiefly to the increased grass competition caused by the nitrogen.

In grazed permanent pastures, very little clover has been present without adding phosphorus. Pastures with complete minerals (PLK) had the most clover, but omission of K had little effect. In the case of an adjacent permanent meadow mowed in June for hay and grazed in late summer and fall, adding either potash or manure with superphosphate and limestone was very influential in promoting large amounts of clover.

On Charlton fine sandy loam soil, minor elements have had no appreciable effects on clover.

Lawnmowing to ½ inch for one season greatly decreased both Ladino and Kent clovers in Kentucky bluegrass-clover seedings, but Kent clover increased slightly under this management in a mixture

with less bluegrass. Cutting to 1 inch was the standard of a comparison.

The amounts of volunteer white clover increased with height when vegetation was mowed during 4 years under four different methods of fertilizing Kentucky bluegrass and Rhode Island bent grasses, cut when 2, 3, 4, and 5 inches in height.

In grassland research, the writer feels that the use of a standardized or single method may defeat the purpose of many experiments.

LITERATURE CITED

1. BEAUMONT, A. B. Experiments with permanent pastures. Mass. Agr. Exp. Sta. Bul. 281. 1932.
2. BLACKMAN, G. E. The ecological and physiological action of ammonium salts on the clover content of turf. Ann. Bot., 48:975–1001. 1934.
3. BROWN, B. A. Technique in pasture research. Jour. Amer. Soc. Agron., 29: 468–476. 1937.
4. FERGUS, E. N. The place of legumes in pasture production. Jour. Amer. Soc. Agron., 27:367–373. 1935.
5. GARDNER, F. D., *et al.* Pasture fertilization. Pa. Agr. Exp. Sta. Bul. 323. 1935.
6. HEIN, M. A., and COOK, A. C. Effect of method and rate of grazing on beef production and plant population of pastures at Beltsville, Md. U. S. D. A. Tech. Bul. 538. 1937.
7. JOHNSTONE-WALLACE, D. B. The influence of grazing management and plant associations in the chemical composition of pasture plants. Jour. Amer. Soc. Agron., 29:441–455. 1937.
8. JONES, MARTIN G. Grassland management and its influence on the sward: II. The management of a clovery sward and its effects. Empire Jour. Exp. Agr., 1:122–127. 1933.
9. PRINCE, FORD S., BLOOD, PAUL T., and PERCIVAL, G. P. Topdressing old pastures. N. H. Agr. Exp. Sta. Circ. 35. 1931.
10. ROBINSON, R. R., and PIERRE, W. H. Response of permanent pastures to lime and fertilizers (1930–1936). W. Va. Agr. Exp. Sta. Bul. 289. 1938.

SUSCEPTIBILITY OF SEEDLING GRASSES TO DAMAGE BY GRASSHOPPERS[1]

WILFORD HERMANN AND ROBERT ESLICK[2]

A PORTION of the grass nursery of the Division of Agronomy, Washington Agricultural Experiment Station, containing 405 selections from 28 species, was seeded in 9-foot rows 2 feet apart on April 11, 1938. The rows were thinned to a 1-inch spacing between May 15 and May 20 and to approximately an 8-inch spacing between July 15 and July 20. Although precipitation was deficient during the spring and early summer months, the grasses made a good growth and those not displaying the winter habit were blooming at the time of the second thinning.

On August 1 strong southwest winds brought large numbers of grasshoppers into the nursery. In all, 187 grasshoppers were caught and identified as to genus and, where possible, as to species (Table 1).[3] Of those examined, 153 were mature grasshoppers and 34 were nymphs. Four species of grasshoppers were found. One hundred ten, or 58.8%, of the insects proved to be the Warrior grasshopper, *Camnula pellucida* Scudd., and the remainder were species of the genus Melanoplus. It is believed that *C. pellucida* was the species observed migrating into the nursery. The Melanoplus species probably developed close to or in the nursery as many of these were observed around the plats previous to the immigration.

TABLE 1.—*Grasshopper species observed in the 1938 grass nursery at Pullman, Washington.*

Grasshopper species	Number	%
Camnula pellucida Scudd.	110	58.8
Melanoplus mexicanus Sauss.	20	10.7
Melanoplus femur-rubrum De G.	17	9.1
Melanoplus bivittatus Say	6	3.2
Melanoplus spp. Stal. (Nymphs)	34	18.2
Total	187	100.0

The species of grasshoppers observed in the Pullman nursery consisted of four of the five reported by Shotwell (6)[4] who found that the most important species of grasshoppers in the crop areas of the North Central States were *Melanoplus bivittatus* Say., *M. differentialis* Thos., *M. femur-rubrum* De G., *M. mexicanus* Sauss., and *Camnula pellucida* Scudd. He observed that the proportions of these species varied from year to year with no individual species maintaining con-

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[3]The authors wish to thank R. D. Eichmann, Assistant Entomologist, Division of Zoology, Washington Agricultural Experiment Station, for his assistance in identifying the grasshoppers.

[4]Numbers in parenthesis refer to "Literature Cited", p. 336.

tinued dominance. In areas utilized chiefly for range purposes, Shotwell reported that Melanoplus and Camnula species were replaced by *Ageneotettix deorum* Scudd., *Encoptolophus sordidus* Burm., *Trachyrachis kiowa* Thos., *Aulocara elliotti* Thos., and others of lesser significance. In all, 30 species of grasshoppers were reported to have economic importance.

Parker, Walton, and Shotwell (5), summarizing grasshopper information, listed the grasshoppers included in this paper as some of the most important in the United States.

Strand (7) placed the damage done to the ranges of Montana by grasshoppers at $1,750,000 for the period 1934–36. The most important species were *Aulocara elliotti* Thos., *Melanoplus mexicanus* Sauss., and *Camnula pellucida* Scudd., respectively. Strand observed that these species attack cultivated crops as well as grasses.

The reports of these investigators indicate that the species of grasshoppers observed in the grass nursery at Pullman are widespread over the north-central portions of the United States.

Observations previous to August 1 indicated that damage to the seedlings by grasshoppers was negligible. After the appearance of the insects in large numbers evidence of damage to the seedlings became rapidly apparent. Nine days (August 9) after the appearance of the immigrant grasshoppers, notes on damage were taken by the authors. The percentage of damage sustained by each selection was determined by estimation of the proportion of the leaves destroyed. Estimations were made independently by the authors and on only three selections was there a disagreement of greater than 10%. These estimations are summarized in Table 2.

Subsequent observations by the authors revealed no changes in the comparative or total amounts of damage sustained by the different species and selections. The spreading of poison bran by members of the Divisions of Agronomy and Entomology on the morning of August 10 resulted in a 60 to 70% kill which probably accounts for the check in the damage done to the seedling grasses.

Tabulation of the notes on damage showed that the species of grasses varied significantly in susceptibility to grasshopper attacks. Five species, *Bromus mollis* L., *Deschampsia elongata* (Hook.) Munro., *Festuca idahoensis* Elmer., *Festuca ovina* L., and *Festuca rubra* var. *commutata* Gaud., displayed complete defoliation from attack by grasshoppers. Ten species, *Agropyron cristatum* (L.) Gaertn. (Standard variety), *Agropyron elongatum* (Host) Beauv., *Agropyron repens* (L.) Beauv., *Agropyron subsecundum* (Link.) Hitchc., *Arrhenatherum elatius* (L.) Mert. and Koch., *Dactylis glomerata* L., *Elymus glaucus* Buckl., *Festuca elatoir* L., *Hordeum bulbosum* L., and *Poa secunda* Presl., showed an average of between 80 and 100% defoliation by grasshoppers. Four species, *Agropyron smithii* Rydb., *Bromus inermis* Leyss., *Elymus canadensis* L., and *Phalaris arundinacea* L., showed an average damage of less than 20% for each species. The other species were intermediate in susceptibility to grasshopper damage. Similar differential feeding of grasshoppers on species of graminaceous crops has been observed in areas where corn and sorghum were grown in adjacent fields (2).

TABLE 2.—*Injury caused by grasshoppers feeding on the foliage of seedling grasses.*

Grass species	Habit of growth	No. of selections	Range of damage, %*	Average damage, %*
Agropyron cristatum (L.) Gaertn. (Fairway)	Spring	23	50–80	69
Agropyron cristatum (L.) Gaertn. (Standard)	Spring	68	30–100	82
Agropyron elongatum (Host) Beauv.	Winter	1	——	80
Agropyron inerme (Scribn. & Smith) Rydb.	Spring	41	20–95	74
Agropyron pauciflorum (Schwein.) Hitchc.	Spring	49	10–80	35
Agropyron pauciflorum (Schwein.) Hitchc.	Winter	4	50–90	78
Agropyron repens (L.) Beauv.	Winter	3	70–90	83
Agropyron smithii Rydb.	Winter	1	——	5
Agropyron spicatum (Pursh) Scribn. & Smith	Spring	21	40–90	69
Agropyron subsecundum (Link.) Hitchc.	Winter	2	——	90
Arrhenatherum elatius (L.) Mert. & Koch.	Spring	5	70–90	82
Bromus inermis Leyss.	Winter	40	5–50	19
Bromus marginatus Nees.	Spring	8	10–70	45
Bromus mollis L.	Winter	1	——	100
Bromus polyanthus Scribn.	Spring	16	10–90	64
Dactylis glomerata L.	Winter	17	50–95	80
Deschampsia elongata (Hook.) Munro.	Winter	1	——	100
Elymus canadensis L.	Spring	2	5–10	8
Elymus condensatus Presl	Winter	3	20–50	30
Elymus glaucus Buckl	Spring	22	60–100	82
Festuca elatior L.	Winter	5	75–90	87
Festuca idahoensis Elmer	Winter	13	——	100
Festuca ovina L.	Winter	5	——	100
Festuca rubra var. *commutata* Gaud.	Winter	10	——	100
Hordeum bulbosum L.	Winter	1	——	95
Phalaris arundinacea L.	Winter	15	0–40	8
Poa ampla Merr.	Spring	10	50–90	76
Poa nevadensis Vasey	Spring	6	40–80	60
Poa secunda Presl.	Winter	3	90–100	97
Secale cereale L. × *Secale montanum* Guss.	Winter	9	40–90	72

*Damage represents an estimation of the proportion of leaves destroyed by grasshoppers.

The Standard variety of *Agropyron cristatum* (L.) Gaertn. was damaged considerably more than the Fairway variety even though the latter has a finer and more leafy growth. Similar differences in damage by grasshoppers have been reported for dent and flint corn (3) and for sorgo, kafir, and milo sorghums (2).

Among species, habit of growth, i.e., winter—entirely vegetative, or spring—first-year flowering, had slight, if any, influence upon their respective susceptibilities. Within a species, however, the selections with the winter habit of growth displayed a greater susceptibility toward grasshopper damage than those with the spring habit of growth. This differential susceptibility of the varying growth habits was best illustrated by *Agropyron pauciflorum* (Schwein.) Hitchc. in which those selections with the winter habit showed 78% damage while those with the spring habit showed only 35% damage. Apparently those selections with the spring habit of growth were more nearly in a mature stage than in a seedling stage of development. Consequently, observations of these plants may approximate the susceptibility of mature plants rather than the susceptibility of seedlings.

Selections within each species displayed wide differences in comparative susceptibility to damage by grasshoppers. Of those species from which over 10 selections had been made, only *Festuca idahoensis* Elmer. and *Festuca rubra* var. *commutata* Gaud. failed to display selection differences in susceptibility to attack by the insects. These two species were completely susceptible. On the other extreme were *Bromus polyanthus* Scribn., *Agropyron cristatum* (L.) Gaertn. (Standard), *Agropyron inerme* (Scribn. and Smith) Rydb., and *Agropyron pauciflorum* (Schwein.) Hitchc. (spring habit) which displayed, respectively, ranges of 80, 70, 75, and 70% damage between selections. Selections from the other species were intermediate between these two extremes in the range of differences which were displayed for susceptibility to damage by grasshoppers. Similar differences in susceptibility to grasshopper attacks have been reported for varieties, hybrids, and top-crosses of corn (2).

Ball (1) has reported that many species of grasshoppers are specific in their host requirements and Mail (4) observed that even so-called omnivorous species of the insect show decided food preferences as long as a surplus of green food is available. Brunson and Painter (2) found that even when forced to consume a single species of crop (corn), grasshoppers preferred some plants to others in open-pollinated varieties. These authors concluded that the genetic composition of a plant influenced its susceptibility to attacks by grasshoppers.

It seems probable that the differential feeding of grasshoppers not only on species but also on selections within the species of grasses in the grass nursery at Pullman may be explained by the abundance of green material available and by the food preferences of the grasshoppers. If the inheritance of a selection influences its susceptibility to attacks by grasshoppers, it may be possible to select strains of grasses which will be more highly resistant to grasshoppers than any now produced.

The extreme differences observed between the seedling grasses in resistance to attacks by grasshoppers may indicate a greater ease of establishment of some species of grass than of others in areas where the insects are sufficiently numerous to do considerable damage without completely destroying the plants.

The damage to grasses noted here was done by species of grasshoppers which are generally distributed and which display a considerable host range (5, 6, 7). For this reason it is believed that the relative susceptibility of these grasses to grasshopper damage, as reported, is probably typical of the grasses throughout the crop regions to which they are adapted. If the predominating species of grasshoppers in an area are species which were not observed in the grass nursery at Pullman, it is probable that other results would be observed.

LITERATURE CITED

1. BALL, E. D. Food plants of some Arizona grasshoppers. Jour. Econ. Ent., 29:679–684. 1936.
2. BRUNSON, ARTHUR M., and PAINTER, REGINALD H. Differential feeding of grasshoppers on corn and sorghums. Jour. Amer. Soc. Agron., 30:334–346. 1938.

3. HUME, A. N. An indication of the relative susceptibility of dent and flint corn to injury by grasshoppers. Jour. Amer. Soc. Agron., 23:1071. 1931.
4. MAIL, G. ALLEN. Food preferences of grasshoppers. Jour. Econ. Ent., 24:767–768. 1931.
5. PARKER, J. R., WALTON, W. R., and SHOTWELL, R. L. How to control grasshoppers in cereal and forage crops. U. S. D. A. Farmers' Bul. 1691:1–14. 1932.
6. SHOTWELL, ROBERT L. Species and distribution of grasshoppers responsible for recent outbreaks. Jour. Econ. Ent., 31:602–610. 1938.
7. STRAND, A. L. Montana insect pests for 1935 and 1936. Mont. Agr. Exp. Sta. Bul. 333:1–39. 1937.

DODDER CONTROL IN ANNUAL LESPEDEZAS[1]

R. E. Stitt[2]

With the introduction of lespedeza into the southern states the field dodder (*Cuscuta pentagona* Engel.)[3] has infested fields of both the annual and perennial lespedezas over widespread areas. This species of dodder was first described by Engelman (3)[4] as occurring near Norfolk, Virginia, in 1842, and has since (7) been found to be prevalent over the eastern half of the United States with lesser infestation ranging to the Pacific Coast and from northern Mexico to Canada. Several European countries (1, 6) have local infestations of field dodder.

The host plants upon which field dodder can grow are numerous, over 100 having been found, this probably being an important factor in adapting the parasite to its present wide habitat and in its persistence. It has been found much more commonly on red clover, alfalfa, and the lespedezas than on other plants.

The following species, some being important cultivated plants and others common weeds, have been observed as hosts of the field dodder. A number of known hosts of minor importance are not included in this list. There may be others of importance as few systematic studies have been made to determine them.

Agropyron repens (L.) Beauv., quackgrass (1)
Amaranthus retroflexus L., pigweed[5]
Beta vulgaris L., beet (1)
Beta vulgaris L. v. *cycla* L., leaf-beet (1)
Brassica oleracea L., cabbage (1)
Cannabis sativa L., hemp (1)
Convolvulus arvensis L., bindweed (1)
Crotalaria sagittalis L.[5]
Cynodon dactylon (L) Pers., bermuda grass (1)
Digitaria sanguinalis (L). Scop., crabgrass[5]
Erigeron canadensis L., horseweed (1)[5]
Hedera helix L., English ivy (1)
Humulus lupulus L., hop (1)
Lespedeza procumbens Michx.[5]
L. sericea (Thunb.) Benth.[5]
L. stipulacea maxim., Korean lespedeza (4)[5]
L. striata (Thunb.) H. & A., common lespedeza (4)[5]
Ligustrum vulgare L., privet (1)
Lolium multiflorum Lam., Italian ryegrass (1)
Medicago sativa L., alfalfa (1)
Nicotiana tabacum L., tobacco (1)
Paspalum distichum L., knotgrass (1)
Perilla nankinensis (Lour.) Decaisne[5]
Plantago lanceolata L., ribgrass (1)
Poa trivialis L., rough bluegrass(1)
Polygonum aviculate L., knotweed (1)[5]
Pueraria thunbergiana (Sieb. & Zucc.) Benth., kudzu[5]
Rhus toxicodendron L., poison ivy[5]
R. typhina L., staghorn sumach[5]
Robinia pseudoacacia L., locust (1)
Rumex acetosella L., sheep sorrel[5]
Salvia coccinea L., sage (1)
Setaria italica (L.) Beauv., foxtail millet (1)
Solanum carolinense L., bull nettle[5]
S. nigrum L., nightshade (1)
S. tuberosum L., potato (1)
Sonchus oleraceus L., sow thistle (1)
Stellaria media L., chickweed[5]
Trifolium incarnatum L., crimson clover (1)
T. pratense L., red clover (1)[5]
T. procumbens L., low hop clover[5]
T. repens L., white clover[5]

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agr. Received for publication January 4, 1939.
[2]Assistant Agronomist.
[3]Many of the manuals give this species under the name *C. arvensis* Beyr. and some list the varieties *typica*, *calycina*, and *verrucosa*.
[4]Figures in parenthesis refer to "Literature Cited", p. 343.
[5]Observed in North Carolina.

The observations given here were made in connection with the development of field dodder on annual lespedezas [*Lespedeza stipulacea Maxim.* and *L. striata* (Thunb.) H. & A.] under the climatic conditions existing on the 60° F isotherm in Piedmont, North Carolina. If differences in the life histories of other hosts are taken into consideration these observations should be more or less applicable.

Under field conditions the seedlings have been found from March to September 1, new ones emerging during every period when the soil surface was moist. Germination studies on blotter paper in a moist chamber revealed that germination is delayed over a period of time. The average germination of 12 samples of 100 seeds each was 15% in 16 days, 33% in 40 days, and 53% in 101 days. Variation between the different samples was great, the highest being 79% and the lowest 24%. In experiments carried on in Pennsylvania by Fulton (5) a few seed germinated on the first and second days, with the largest number on the third day and scattered germination thereafter for 66 days. Germination varied from 3 to 40%. Seed kept in moist earth was lower in number of viable seed than those stored in dry air. Fulton also found that seed at maturity germinated about as well as when tested 9 months later.

To observe development in the field 20 seedlings which had just emerged were placed at individual locations in Korean lespedeza. Only two of these attached themselves to a host, the others dying after a few days. Seedlings under similar conditions out of reach of a host lived from 4 to 9 days while those in a germinator lived from 10 to 15 days after germination.

On Korean lespedeza infestation from a single seedling spread 2 feet in 12 days from time of attachment to the host and a radius of 10 feet was reached before growth was stopped by maturity.

Dodder stems 16 inches in length were taken into the laboratory and left in the shade on a table. These stems produced 3 inches of new growth in 10 days. The stems died from the opposite end at the rate of 11 inches in 6 days, 14 inches in 11 days and were all dead in 16 days. When placed in the laboratory the plants were a light yellow in color. After 3 or 4 days in the shade a small amount of green coloring matter was observed around the nodes.

Dodder bloomed in 21 days and seed was mature in 38 days from the germination date. Blooming was continuous over a period of 2 to 3 months, varying with the maturity of the host plant. The parts of the dodder plant adjacent to the seed balls die as the seed matures, but the ends of the stems continue to grow as long as the host is alive.

REMOVING DODDER FROM LESPEDEZA SEED

Under Tennessee conditions Essary (4) found that most of the dodder seed can be removed from lespedeza seed by using a lower screen with 16 mesh to the inch and proper adjustment of the air current. A 12-mesh screen was used as the upper screen in cleaning the Korean and common varieties and a 10-mesh screen for the Kobe variety.

Lespedeza seed lots containing considerable amounts of dodder were obtained from the seed-growing area in Piedmont, North Carolina and a number of screen combinations were tried in an attempt to remove the dodder used. The results of these tests are given in Table 1.

TABLE 1.—*Number of dodder seed per pound of sample lespedeza seed before and after cleaning and percentage of lespedeza seed removed as screenings.*

Number of dodder seed per pound of uncleaned lespedeza	Diameter of lower screen openings in inches	Number of dodder seed per pound of cleaned lespedeza	Lespedeza seed removed as screenings, %
	Korean Lespedeza		
20,145	1/18	7,830*	8.47
20,145	1/17	5,490	6.09†
20,145	1/16	1,020	13.97
20,145	1/15	765	42.60
20,145	1/14	170	54.89
	Kobe Lespedeza		
13,600	1/18	8,370	—
8,370	1/17	4,590	—
8,370	1/16	3,910	—
	Common Lespedeza		
2,430	1/16	990	—

*Seed counts by the Seed Laboratory, Bureau of Plant Industry, U. S. Dept. of Agriculture.
†The lower percentage of lespedeza seed removed by the screen with 1/17-inch openings as compared with the 1/18-inch can be accounted for by possible variation in the size of lespedeza seed in the different lots drawn from the bulk sample.

The lot of Korean lespedeza seed contained 4.79% dodder, or 20,145 seed per pound of uncleaned lespedeza. Considerable dodder seed passed through a screen with 1/18-inch perforations. As many of the dodder seed were larger than 1/16 inch in diameter it was necessary to use larger screens, but even using 1/14- and 1/15-inch openings which also permitted the passage of lespedeza seed failed to remove all of the dodder. The cleanest sample of lespedeza seed contained 170 dodder seed per pound which would be enough to thoroughly infest a field. In getting a sample this clean it was necessary to screen out about 54% of the lespedeza seed, as seed from which the hull has been removed are present in all lots of threshed lespedeza, these being similar in size to dodder. A large amount of the lespedeza seed in the screenings can be recovered, but not all the dodder seed can be removed. Lespedeza screenings containing 16,650 dodder seed per pound when recleaned over a screen with 1/17-inch perforations contained 7,020 dodder seed per pound. Recleaning the seed from this operation over a screen with 1/16-inch perforations lowered the number of dodder seed to 930 per pound and repeating again over the 1/16-inch screen to 170 per pound.

While the cleaning experiments with the common and Kobe varieties were not as extensive as those with Korean, the results obtained gave indications of being no more effective.

As a fanning mill using two screens and an air blast was the only cleaning method used these experiments should not be considered conclusive as other methods may be more adaptable.

METHODS OF CONTROL

Sulfuric acid in a 3% solution by weight has been recommended for field dodder control in lespedeza by Essary (4) in Tennessee and a 5% solution was found effective for dodder by Brown and Streets (2) in Arizona.

In order to study the cost and effectiveness of several methods of dodder control in annual lespedeza different rates of application of several chemicals were made on 125 square foot plats in triplicate.

Solutions of sulfuric acid of 2.5, 3.3, and 5.0% by weight with water, killed both dodder and lespedeza when the plants were thoroughly moistened. Ammonium thiocyanate was found to be effective in amounts of 1 pound or more in 2 gallons of water per square rod, killing both dodder and lespedeza.

"Atlacide", a proprietary mixture usually containing sodium chlorate and calcium chloride, applied at the rate of 1.5 pounds in a gallon of water per square rod killed all plants on the area covered with the spray.

Sodium nitrate, potassium chloride, and ammonium sulfate did not harm either lespedeza or dodder when 6 pounds were applied in 12 gallons of water per square rod.

To obtain comparative cost figures on different methods of dodder control, areas of ¼ acre each having as nearly uniform dodder infestation as it was possible to find were laid out.

The control methods were started in June soon after the grain crop had been removed from the field. At this time the dodder was located in more or less scattered areas varying from 10 to 20% of the plat. Retreatment was necessary at intervals of 9 to 30 days, varying with seasonal moisture conditions. During wet weather considerable germination of dodder seeds was observed. It should be emphasized that very thorough inspection is necessary at the time of each treatment which keeps the labor costs high even though the infestation of dodder has been lowered. Three methods were found to be of value, each having certain advantages and disadvantages. A comparison of labor and materials used in the experiment are given in Table 2.

The blow torch method in which the plants are wilted proved to be the most satisfactory way to kill dodder. The amount of labor used was no more than that required for other methods. Fuel costs were lower than the usual necessary costs for materials in applying chemicals. Seed balls of the dodder plant are easily destroyed by this method. The lespedeza to which the dodder plants are attached is destroyed, reducing the area considerably in heavy infestations.

Another satisfactory way to control dodder is to cut out by hand the infested parts of the plants and place them in a bag for removal from the field. The labor required is about twice that of destroying with the blowtorch. However, labor is the only item and the economy of the method will depend on the relative prices of labor and materials between the different methods.

Spraying with chemicals requires an outlay for labor similar to that of control with a blow torch. The amount of materials used will vary considerably with the size of growth to which they are applied, raising the costs of late applications.

TABLE 2.—*Labor and materials necessary to destroy 1 acre of dodder infestation in Korean lespedeza.*

Date	Man hours	Material	Infestation reduction, %
Blow Torch			
June 22	9.1	3.6*	15
July 8	8.2	5.4	20
Aug. 3	7.3	5.4	5
Aug. 20	4.8	5.4	5
Totals	29.4	19.8	45‡
Chemical Spray lbs. "Altacide"			
June 27	8.5	36†	20
July 27	7.3	58	15
Aug. 5	7.3	54	5
Aug. 20	5.4	44	5
Totals	28.5	192	45‡
Hand Removal			
June 22	15.1	—	10
July 8	16.0	—	15
July 27	13.3	—	10
Aug. 27	14.5	—	5
Totals	58.9		40‡

*Gallons of kerosene.
†Pounds of "altacide."
‡The use of either the blowtorch or chemical sprays killed all plant growth on the infested areas. Total infestation on the area controlled by hand removal may represent some duplication of infested area as the lespedeza recovered from the treatments, and allowed reinfestation by germinating seeds.

If the cost of the chemical used is low enough this method may have some place in dodder control. Small amounts of waste sulfuric acid are available at creameries and can be obtained at little expense. This can be used as effectively as commercial sulfuric acid. Precautions must be taken to avoid burns to the operators. None of the chemicals destroyed dodder seed in the amounts applied.

If the infestation of dodder is heavy enough to make the costs of applying these control methods so high as to be prohibitive, some other methods may be followed, such as rotating with a crop on which dodder will not grow. Field dodder does not grow on soybeans or cowpeas so these can be used in rotations in place of the legumes which are readily infested. The various cereals and corn are not attacked.

Seed will live in the soil for five years or longer so that control practices must be followed over a long period of time. Close pasturing has been observed to control dodder on farms. Inspection is necessary in pasturing infested stands to remove any dodder not eaten as growth is often found on unpalatable host plants.

SUMMARY

1. The life history of field dodder on annual lespedeza is given with a list of economic host plants. This species has been found growing on

a number of host plants some of which are listed. Germination under field conditions takes place throughout the growing season. Growth is rapid and blossoms were found 21 days after attachment to the host.

2. Seed of field dodder cannot be entirely removed from annual lespedeza seed by screens.

3. Dodder growing in the field can be destroyed by several methods. The most economical will depend on labor and material costs. The plants can be burned with a blow torch, cut out by hand, or sprayed with chemicals.

4. Effective chemicals were (a) a 2.5% solution by weight of sulfuric acid with water; (b) 1 pound of ammonium thiocyanate in 2 gallons of water, and (c) 1½ pounds of "Atlacide" in 1 gallon of water. These killed all plants of both dodder and lespedeza when thoroughly moistened by spraying.

5. Spraying with chemicals does not prevent dodder seed production if seed balls have started to form.

LITERATURE CITED

1. BONAVENTURA, G. *Cuscuta pentagona*. Engel., su nuove matrici. Boll. R. Inst. Sup. Agr., Pisa, 8:623–627. 1932.
2. BROWN, J. G., and STREETS, R. B. Sulphuric acid spray. A practical means for the control of weeds. Ariz. Agr. Exp. Sta. Bul. 128. 1928.
3. ENGELMANN, GEORGE. A monography of the North American Cuscutineae. Amer. Jour. Sci., 43:333–345. 1842.
4. ESSARY, SAMUEL H. Control of dodder in lespedeza. Tenn. Agr. Exp. Sta. Circ. 22. 1928.
5. FULTON, H. R. Germination of seed of clover dodder. Penn. Agr. Exp. Sta. Ann. Rpt., 1911–12:250–251. 1912.
6. HANF, M. Beobachtungen über das Auftreten von Cuscuta (seide)—arten als gartenschädlinge. Gartenbauwiss, 11:555–568. 1938.
7. YUNCKER, T. G. The genus Cuscuta. Mem. Torr. Bot. Club, 18 (2):162–163. 1932.

THE DETERMINATION OF REDOX POTENTIALS OF SOILS[1]

N. J. Volk[2]

BEFORE beginning a study of the relation of oxidation-reduction (redox) potentials of soils to plant growth and to various chemical and biological processes of the soil, it was deemed advisable to investigate existing methods of determining the redox potentials (Eh) of soils. Preliminary studies soon revealed that none of the existing methods adequately fulfilled the requirements which were believed necessary for the type of investigation contemplated. Methods, to be satisfactory for collecting, preserving, and analyzing samples of soil for redox studies, should (a) inhibit bacterial action so as to prevent reduction within the sample after removing it from the field; (b) prevent oxidation of reduced compounds existing in the soil; (c) refrain from appreciably dissolving substances existing as solid matter in the soil; (d) and result in the redox potential obtained being the same as that existing in the soil in its natural state, or be comparable to it so that one soil can be compared with another.

The investigation reported herein was conducted for the purpose of developing a satisfactory method for determining soil redox potentials.

METHOD OF PRESERVING SAMPLES OF SOIL

Soil-water suspensions containing easily decomposable organic matter will be reduced materially if allowed to stand more than 24 hours at temperatures of 80° to 90° F. Conversely, soil-water suspensions containing easily oxidizable substances will become oxidized appreciably in a few minutes if exposed to atmospheric oxygen, especially if agitated. A number of workers (1, 2, 8, 9, 10, 12)[3] suspended soils in 0.1 N H_2SO_4 and thereby prevented bacterial reduction, but only two, Kohnke (8) and Willis (14), considered the expulsion of air with nitrogen gas a necessary procedure for the prevention of oxidation during analysis. On the other hand, a few investigators disregarded the possibility of oxidation or reduction of the soil during analyses (3, 5, 6, 7, 11, 13).

Since the type of investigation contemplated at this Station involved the collecting of samples from remote locations in the state, thus making it impossible to determine their redox potentials for at least 72 to 96 hours, a method had to be perfected which would prevent oxidation or reduction of samples of soil during transit and storage.

Oxidation of the soils during transit and in storage was inhibited by submerging them in oxygen-free water and corking tightly with paraffined corks.

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[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication January 7, 1939.

[2]Soil Chemist.

[3]Reference by figures in parenthesis is to "Literature Cited", p. 351.

A number of investigators have used 0.1 N H_2SO_4 to add poise to the system and to prevent reduction. However, results obtained in this laboratory soon revealed that redox measurements obtained through the use of 0.1 N H_2SO_4 as a preservative were not comparable to those obtained with soil-water suspensions (Table 1). It is believed that the solvent action of 0.1 N H_2SO_4 on the solid phase of the soil brought materials into solution not ordinarily in an active state in the soil.

TABLE 1.—*The redox of potentials of samples of soil suspended in water as compared with those suspended in 0.1 N H_2SO_4.*

Soil	Eh of soils in millivolts*		Difference in millivolts between the results obtained with the two suspension mediums§
	Suspended in water†	Suspended in 0.1 N H_2SO_4‡	
Wehadkee clay	426	659	233
Holly clay	464	674	210
Leaf fine sandy loam	464	648	184
Hanceville fine sandy loam	468	614	146
Susquehanna sandy loam	476	771	295
Amite clay loam	479	851	372
Houston clay	480	606	126
Oktibbeha clay	480	682	202
Durham fine sandy loam	485	811	326
Davidson clay loam	489	834	345
Norfolk fine sandy loam	490	829	339
Cecil fine sandy loam	494	812	318
Colbert clay loam	500	677	177
Huntington clay loam	501	852	351
Decatur clay	524	840	316
Eutaw clay	532	643	111

*Analyses conducted in atmosphere of nitrogen.
†Eh adjusted to pH 6.0 to avoid large adjustment.
‡Eh adjusted to pH 3.0 to avoid large adjustment.
§These differences should be nearly constant if the methods are to be considered comparable.

Since 0.1 N H_2SO_4 could not be used, a number of preservatives, disinfectants, and disinfecting methods were tried in an attempt to find some way in which to inhibit bacterial reduction and yet obtain redox measurements comparable for all soils. Mercury compounds, copper compounds, toluene, alcohol, steam, heat, and refrigeration are a few of the things tried. All chemical disinfectants tried in sufficient concentration to stop bacterial growth were found to exhibit variable and inconsistent effects on the existing redox of the soil. However, cooling the soil-water suspensions to just above the freezing point practically inhibited bacterial action and proved to be a convenient method of preservation. Results of several tests with refrigeration are given in Table 2.

USE OF NITROGEN GAS TO PREVENT OXIDATION

Apparently very few investigators found it necessary to use nitrogen gas to expel oxygen from suspensions of soil during analyses so as

TABLE 2.—*The prevention of bacterial reduction through the use of refrigeration.*

Soil	Treatment of 1:3 soil-water suspension	Eh in millivolts at pH 6.0				Total millivolts reduction taken place during standing	
		At 35° F		At 85° F			
		Standing 5 hours	Standing 48 hours	Standing 5 hours	Standing 48 hours	At 35° F	At 85° F
Congaree	None	551	550	548	493	1	55
Waynesboro		492	489	488	440	3	48
Congaree	1 gram ground filter paper added per 100 cc of suspension	514	511	516	468	3	48
Waynesboro		489	490	489	443	0	46
Congaree	1 gram sucrose added per 100 cc of suspension	516	512	515	424	4	91
Waynesboro		473	478	476	−29	0	505
Congaree	1 gram vetch added per 100 cc of suspension	498	498	497	−162	0	659
Waynesboro		435	439	434	−148	0	582

to prevent oxidation. A great many arable soils tested at this laboratory indicated that as a general rule the amount of oxidation taking place during the analyses was negligible, but on the other hand, soils in a reduced state were found to oxidize considerably during analyses if air was not expelled with nitrogen.

Powdered vetch was added to 1:3 soil-water suspensions in flasks fitted with Bunsen valves. Another set of suspensions was prepared without the addition of vetch. After standing at room temperature for 3 weeks one portion of each of these samples was shaken for 2 hours with 20 cc of nitrogen per 100 cc of suspension and was analyzed for redox potential in an atmosphere of nitrogen gas. A second portion was shaken for 2 hours with 20 cc of air per 100 cc of suspension and then analyzed for redox potential in an atmosphere of nitrogen. The results are given in Table 3.

These results show that for soils in a reduced state it is essential that nitrogen gas be used to keep out the air and thereby prevent oxidation. Since it is difficult to tell if a sample of soil is in a reduced state under field conditions, all analyses for redox measurements conducted at this laboratory were carried out in an atmosphere of nitrogen.

Eh/pH RELATIONSHIP IN SOILS

The theoretical factor of 59 millivolts at 25° C for the relationship of potential to pH holds extremely well where one is dealing with the potential of hydrogen in soils, but in the case of the Eh of soils measured with a blank electrode one is dealing with the potential of

TABLE 3.—*The Eh values of soil suspensions shaken with a definite quantity of air compared with the Eh values when shaken with nitrogen gas.*

Total number of soils tested	Treatment of 1:3 soil-water suspensions prior to shaking them with air or nitrogen	Quantity of air or nitrogen shaken with 100 cc of soil-water suspension for 2 hours	Average Eh in millivolts at pH 6.0*	Increase in Eh value caused by shaking the soil-water suspension with air
41	Kept cold (35° F) to prevent bacterial reduction prior to analyses†	20 cc nitrogen 20 cc air	527 531	4
6	Kept at 80° F 3 weeks out of contact with air, thus causing an average reduction of 117 mv.	20 cc nitrogen 20 cc air	509 517	8
6	1 gram vetch added per 100 cc suspension and kept at 80° F 3 weeks out of contact with air thus causing an average reduction of 593 mv.	20 cc nitrogen 20 cc air	23 79	56

*Analyses conducted in atmosphere of nitrogen.

†These are arable soils collected at random from the six soil provinces in Alabama. The samples were kept out of contact of the air until the above analyses were made.

innumerable substances in one composite mass. Thus it is the exception rather than the rule that a soil will have an Eh/pH relationship of 59. A study of 132 different types of soil in Alabama showed that the Eh/pH factor, even within close range of the initial pH, varied from 58 to 101 with an average of 66 (Table 4).

TABLE 4.—*The Eh/pH relationship for 132 Alabama soils.*

Range of Eh/pH factor in millivolts	Number of samples	Percentage of samples
58 to 60, inclusive	38	28.8
61 to 70, inclusive	74	56.1
71 to 80, inclusive	10	7.6
81 to 90, inclusive	6	4.6
91 to 100, inclusive	3	2.3
101 to above	1	0.7

Peech and Batjer (9) and Bradfield, Batjer, and Oskamp (2) used the factor of 80 for all soils, while Kohnke (8) used the theoretical factor of 59. No great error will be made if one uses a common factor for all soils, providing there is only a small variation in pH between soils. The soils studied at this laboratory varied from pH 4.0 to 8.0, consequently, great errors would be introduced by using a common factor, such as 59 or 80. For example, one particular soil had an Eh of 436 at pH 8.12 and another had an Eh of 667 at pH 4.23. If the common factor of 59 is used and the Eh is adjusted to pH 6.0, the values obtained are 561 and 563, respectively, but when the correct

factors of 59 and 96, respectively, are used the Eh values at pH 6.0 are 561 and 497. Thus, instead of having identical Eh values as shown by using the common factor of 59, these soils actually differed by 64 millivolts which is approximately 13 times the experimental error. Consequently, for all studies on the problem of oxidation and reduction potentials in soils, the Eh/pH factor was determined for each individual soil between pH 6.0 and the pH at which the Eh was determined.

CAUSE FOR DRIFT OF POTENTIAL IN POORLY POISED SOILS

Peech and Batjer (9) offered data to show that potential drift (adaptation lag) in poorly poised soils was due to the past history of the electrode; that is, if the electrode had been immersed previously in a solution having a higher or lower potential than the soil to be tested, it would require from a few minutes to several hours for that particular electrode to come into equilibrium with the soil—the time required depending on the poise of that particular soil. However, Burrows and Cordon (4) disagreed with Peech and Batjer and claimed that the drift was caused by the agar bridge and that a liquid KCl bridge must be used to overcome the difficulty. The findings at this laboratory support those of Peech and Batjer and the results are given in Table 5.

TABLE 5.—*The cause for potential drift in poorly poised soils immediately following the insertion of the blank electrode into the soil suspension.*

Soil studied	Eh of soil in millivolts at pH 4.0		
	Soils in equilibrium with nitrogen	Soils in equilibrium with nitrogen but the agar bridge removed momentarily and treated with a solution of Eh 612 at pH 4.0*	Soils in equilibrium with nitrogen but the blank electrode removed momentarily and treated with a solution of Eh 612 at pH 4.0†
Davidson	586	581	611
Congaree	542	548	610
Decatur	505	511	610
Huntington	522	524	604
Hanceville	546	549	605
Waynesboro	532	534	608
Average of all soils	539	541	608

*The agar bridge was removed from the soil suspension, immersed ½ minute in a buffer at pH 4.0 and Eh 612. It was then simply *rinsed* and replaced in the soil suspension and another Eh reading taken immediately. The blank electrodes were not removed during this operation.

†The blank electrodes were treated exactly as the above described treatment for the agar bridges, and then on returning them to the soil suspensions another Eh reading was taken at once.

It is interesting to note that treatment of the agar bridge did not affect the Eh value, but that the treatment of the blank electrodes caused an initial reading to be obtained which was almost identical with the buffer in which they had been placed for ½ minute.

After studying a large number of soils it was found that the Eh value became very nearly constant after 2 hours; thus, all determina-

tions of Eh value in water suspensions were made after the blank electrodes had been in contact with the suspension for 2 hours or more. Results reported by Burrows and Cordon (4) could not be duplicated in this laboratory.

TYPE OF BLANK ELECTRODES MOST SUITED FOR SOIL SUSPENSIONS

During the early part of the present investigation dealing with oxidation and reduction in soils, platinum foil electrodes about ¾ cm square were used. Apparently for no reason at all, electrodes which had been used previously and found to be satisfactory would suddenly be off 25 to 100 millivolts from the other three electrodes in the same suspension. (Four electrodes were used simultaneously in each suspension to insure accurate results.) After considerable trouble of this nature it was observed on removing the electrodes from the suspension that the faulty one usually had a few little plant roots clinging to it. After removing these plant roots and returning the electrode to the original suspension it would usually come to equilibrium with the other electrodes. This difficulty with roots was largely overcome through the use of smooth, straight, wire electrodes about 2 cm in length.

Electrodes that differed over 5 millivolts from the other three in each set of four were discarded and cleaned before using again. The results given in Table 6 indicate the kind of checks one can expect when using properly constructed, properly cleaned, smooth wire platinum electrodes.

TABLE 6.—*A comparison of Eh readings obtained between blank electrodes, 88 electrodes being used, and 280 tests being made on 132 different soils.*

Difference in millivolts between two freshly cleaned electrodes immersed in the same soil suspension	Percentage of tests
Perfect agreement between electrodes	40
1 millivolt difference between electrodes	24
2 millivolt difference between electrodes	21
3 millivolt difference between electrodes	7
4 millivolt difference between electrodes	4
5 millivolt difference between electrodes	1
Over 5 millivolt difference between electrodes	3*

*These 3% were discarded and cleaned before being used again.

The cause for blank electrodes being over 5 millivolts off was commonly found to be due to minute cracks in the seal which could be detected through the use of a magnifying glass. Many times the cracks were so small as to cause an error of only 10 or 15 millivolts, yet the electrode would be off that much consistently. The glass seals should be inspected with a lens at frequent intervals so that electrodes that are cracked will not be discarded for cleaning but will be discarded until reconstructed.

DETAILS OF METHOD FINALLY ADOPTED FOR COLLECTING, STORING, AND ANALYZING SOILS FOR REDOX POTENTIALS

Soils removed from the field were placed immediately in 60-cc bottles containing 30 cc of water saturated with nitrogen gas. Enough soil was added to push the water into the neck of the bottle—this insured about the same size sample of soil at all times and reduced oxidation to a minimum by expelling the air. After the bottles were tightly closed with paraffined corks, they were placed in an insulated box containing dry ice and cooled to about 35° F. All samples were kept at this temperature until they were analyzed for redox potential.

In the laboratory the soil suspensions were transferred to 250-cc flasks, 100 cc of oxygen-free water added, the air displaced with nitrogen, the flasks stoppered, and the suspension shaken vigorously until the soil was dispersed. This operation usually required 1 minute for sandy soils and about 10 minutes for plastic soils. The suspension was allowed to stand for ½ minute and then 50 cc poured into the original 60-cc bottle, the air displaced with nitrogen, and the bottle placed in a mechanical shaker for 2 hours. At the end of this period the sample was again stored in a refrigerator until it could be analyzed. Samples were usually analyzed immediately on being removed from the shaker or within 48 hours after being placed in the refrigerator following dispersion. (Ordinarily, the 10 cc of air remaining in the bottle need not be replaced with nitrogen gas except when soils are highly reduced, Table 3.)

The actual determinations of redox potential and pH were made in an atmosphere of nitrogen[4] by aspirating the suspension with the gas by the use of goosenecked carbon filter funnels of 80-cc capacity. A paraffined cork carrying one tested glass electrode and four blank platinum wire electrodes was inserted into each funnel. Readings were made at the end of 2 hours with an L. and N. 7660 potentiometer. In order to expedite matters where large numbers of samples had to be analyzed, a battery of 30 completely equipped aspirators was kept running simultaneously. All blank electrodes and glass electrodes were constructed in this laboratory.

SUMMARY

The purpose of this investigation was to find a suitable method of preserving samples of soil for redox measurements and to develop an accurate method for determining the oxidation-reduction potentials of soils. The results are summarized as follows:

1. All chemical preservatives tested which effectively inhibited bacterial action in soils also altered the Eh of the soil to such an extent that the results were no longer comparable.

2. Cooling the soils to just above the freezing point was found to be a very effective preservative method.

[4]During a recent conversation with Dr. R. W. Cummings of Cornell University the idea was advanced that sufficient oxygen might be contained in commercial nitrogen to affect the results obtained when determining oxidation-reduction potentials of soils. Several tests were made using different cylinders of nitrogen and highly reduced soils and in all cases the error was less than 5 millivolts per hour when unwashed nitrogen was bubbled through the soil suspensions.

3. Oxidation of reduced compounds in the soil was prevented by the use of water saturated with nitrogen and by performing analytical operations in an atmosphere of nitrogen.

4. The Eh/pH relationship, even within close range of the initial pH, was found to vary from 58 to 101 millivolts for different soils, thus the Eh/pH relationship was determined for each soil studied and correction in Eh made accordingly for differences in pH.

5. Potential drift was found to be due to previous treatment of the blank electrodes and not to the agar bridge.

6. Smooth straight wire platinum electrodes 2 cm in length were found superior to foil since roots clinging to the foil electrode caused misleading results.

7. Details are given for the analytical procedure finally adopted. Results agreeing within 5 millivolts by this method are considered satisfactory.

8. A total of 15 to 20 soils can be analyzed per hour for Eh values by using a battery of 30 aspirators involving 30 glass electrodes and 120 blank electrodes.

LITERATURE CITED

1. BATJER, L. P. Seasonal variation in oxidation-reduction potential of some orchard soils. Amer. Soc. Hort. Sci. Proc., 30:98–101. 1933.
2. BRADFIELD, R., BATJER, L. P., and OSKAMP, J. Soils in relation to fruit growing in New York. Part IV. The significance of the oxidation-reduction potentials in evaluating soils for orchard purposes. Cornell Univ. Agr. Exp. Sta. Bul. 592. 1934.
3. BROWN, L. A. Oxidation potentials in soils: Principles and electrometric determination. Soil Science, 37:65–76. 1934.
4. BURROWS, W., and CORDON, T. C. The influence of the decomposition of organic matter on the oxidation-reduction potential of soils. Soil Science, 42:1–10. 1936.
5. DARNELL, M. C., and EISENMENGER, W. S. Oxidation-reduction potentials of soil suspension in relation to acidity and nitrification. Jour. Agr. Res., 53:73–80. 1936.
6. HEINTZE, S. G. The use of the glass electrode in soil reaction and oxidation-reduction potential measurements. Jour. Agr. Sci., 24:24–41. 1934.
7. HERZNER, R. A. Beitrage zur physikalischen chemie unserer kulturboden. III. Absorptions and redoxpotential. Ztschr. Plansenernahr., Dungung u. Bodenk., 18A:249–264. 1930.
8. KOHNKE, H. E. L. Some factors affecting the oxidation-reduction potentials in soils. Ohio State Univ. Press. 1935.
9. PEECH, M., and BATJER, L. P. A critical study of the methods for measuring oxidation-reduction potentials of soils, with special reference to orchard soils. Cornell Univ. Agr. Exp. Sta. Bul. 625. 1935.
10. ———— and BOYNTON, D. Soils in relation to fruit growing in New York. Part X. Susceptibility of various New York orchard soils to reduction upon water-logging. Cornell Univ. Agr. Exp. Sta. Bul 667. 1937.
11. SMOLIK, L. Contribution to the variability of redox-potentials of soils. Rocnik X: Sesit 3:272–275. 1935.
12. STEPHENSON, R. E., SCHUSTER, C. E., and SPULNIK, K. J. Oxidation-reduction potentials in orchard soils. Jour. Amer. Soc. Agron., 30:91–96. 1938.
13. STURGIS, M. B. Changes in oxidation-reduction equilibrium in soils as related to the physical properties of the soil and the growth of rice. La. Agr. Exp. Sta. Bul. 271. 1936.
14. WILLIS, L. G. Some potential changes induced by liming suspensions of a peat soil. N. C. Agr. Exp. Sta. Bul. 47. 1934.

THE SOIL MOISTURE RELATIONSHIP OF EUROPEAN BINDWEED GROWING IN CORN[1]

A. L. Bakke[2]

THE European bindweed (*Convolvulus arvensis* L.) with its deeply penetrating root system has a distinct advantage over plants whose roots do not grow so deeply. The competition which must ensue where bindweed is grown in corn is centered directly about the soil moisture and the rainfall. Clements, Weaver, and Hanson (6)[3] state that two plants growing together do not compete as long as the water content and nutrients, temperature, and the light are in excess of the needs of both. When the roots of one enter the area from which the other draws its water supply, or the foliage of the one begins to overshadow the leaves of the other, the reaction of the former modified unfavorably the factors controlling the latter and competition is initiated. The successful plant is able to secure its requirements first.

Corn planted during the early part of May in soil infested with bindweed is able to thrive for a time as the bindweed is rather late in starting in the spring. Later, bindweed is in active competition with the corn for soil moisture, but as long as there is sufficient moisture in the upper soil corn grows satisfactorily, particularly when cultivation is sufficient to keep the bindweed from interferring with the aerial development of the corn plant. As the season progresses, the corn on an infested bindweed area is noticeably smaller than where no bindweed is present. When the corn is picked in the fall the yield in the bindweed areas is usually much less than where the field is free of this weed.

In the 1-square-rod experimental plats at Hawarden, Iowa, in 1932, it was found that plat 74 planted to corn and hoed twice a week throughout the season yielded 27.9 pounds, while from plat 94, also in corn and used as a control, 3.5 pounds were husked. Plat 201, hoed once a week, produced 24.5 pounds of corn in 1932 and 33 pounds in 1933, while the control plat (No. 143) showed a yield in the two years of 10 pounds and 16 pounds, respectively.

Competition such as exists between the corn and the bindweed is largely concerned with the water balance forces. If the roots of bindweed, a perennial, are present in the soil to a considerable depth, they will have the advantage over corn, an annual, as the corn roots are all formed during the current year.

The present investigation represents an attempt to determine the soil moisture relations of the bindweed in well-established areas when grown in association with corn.

METHOD

Two areas, one in a thickly infested area of bindweed in corn and the other free of bindweed, were chosen for the present investigation of the soil moisture

[1]Journal Paper No. J-604 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project 484. Received for publication January 14, 1939.

[2]Research Professor, Botany and Plant Pathology Section.

[3]Figures in parenthesis refer to "Literature Cited", p. 357.

relations. During the years 1933 and 1934, the same areas were used. In 1935, it became necessary to move about 20 rods further north as the first field was seeded to oats. The second field was as nearly as possible comparable to the first. The loess soil was found to have a water-holding capacity of 56.22%. The wilting coefficient was found by direct determination to be 9.07%, according to the Briggs and Shantz (4) method.

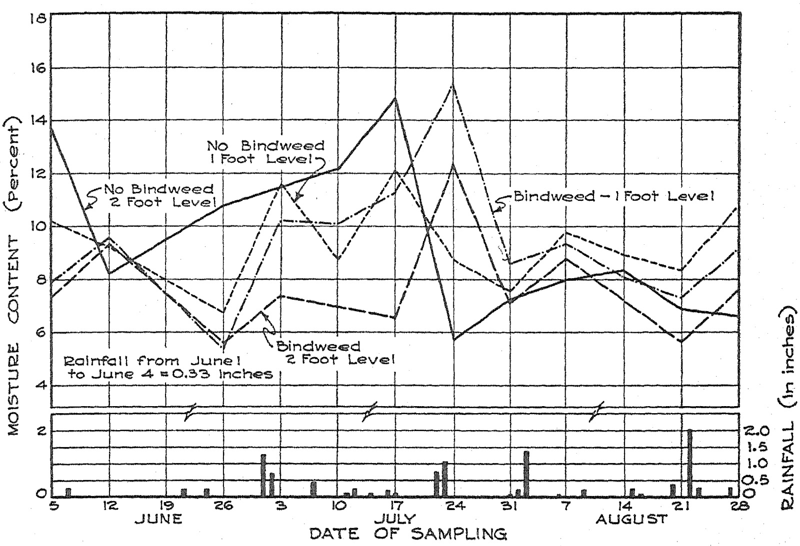

Fig. 1.—Moisture content of soil taken from corn field containing European bindweed and free from bindweed at 1- and 2-foot levels. Hawarden, Iowa. 1933.

As the principal feeding roots of both bindweed and corn are in the upper 2 feet of soil, it was decided to obtain the soil samples at weekly intervals during the time of active growth of the two. In 1933 the sampling was begun the early part of June and continued until the latter part of August, but in 1934 and 1935 the samplings were begun in July and continued until the latter part of September. The duplicate soil samples were immediately placed in covered metal soil containers and dried to constant weight in an electric oven at a temperature of 100° C. Rainfall records were kept throughout the season.

1933 RESULTS

From an examination of Fig. 1 it is found that at both the 1- and 2-foot levels the soil moisture was below the wilting coefficient for a greater portion of the time. In the case of the 1-foot level the two curves almost coincided. During the latter part of July the soil moisture of the bindweed-infested area rose considerably above the wilting coefficient. A possible explanation may be attributed to the aerial portion retaining a greater amount of the rainfall than where no bindweed was present. During the month of August there was not much difference in the soil moisture in the two areas.

The soil moisture content at the 2-foot depth showed considerably more moisture in the area free of bindweed during most of June and the early part of July. During August the soil moisture content of the two plats was almost the same.

According to Reed (11), June 1933 was the warmest and driest June on record. July had a higher temperature average and the precipitation was below average. August had a temperature below average and a precipitation which was light. The summer of 1933 was the fourth warmest on record.

From the data submitted during 1933 for the first foot, the rainfall during June and July had little effect on the moisture content. The few light rains from July 10 to July 24 brought about a considerable increase in the moisture content of the bindweed areas. It is possible that the bindweed plants by preventing run-off of the rain produced the increase.

The 1934 graph (Fig. 2) of the moisture relations of the soil in a bindweed area and in one free of bindweed at a depth of 1 foot showed a

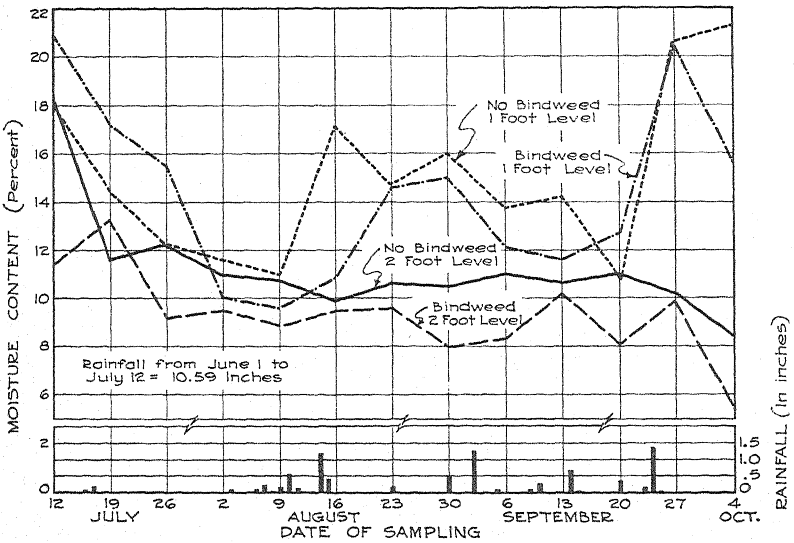

Fig. 2.—Moisture content of soil taken from corn field containing European bindweed and free from bindweed at 1- and 2-foot levels. Hawarden, Iowa. 1934.

tendency for the latter to have more moisture in the soil than the former. At the 2-foot level the two curves followed each other at about the same variation but both were below the wilting coefficient. There was little increase in the soil moisture content at the 1-foot depth after the rain of August 30 and September 1 even though the aggregate amount was 1.74 inches. The high point reached for both areas at the 1-foot level on September 27 was no doubt a result of the heavy rain on September 24 along with lower evaporating environment.

The summer of 1934 (11) was the hottest summer on record. The month of May was the warmest on record. The precipitation during

June and July was a little above normal. August was also dry and hot, but the temperature and precipitation were slightly above normal.

On an examination of Fig. 3, it is noticed that the moisture content was above the wilting coefficient for both depths throughout the entire period of 1935. From August 15 until the end of the season there

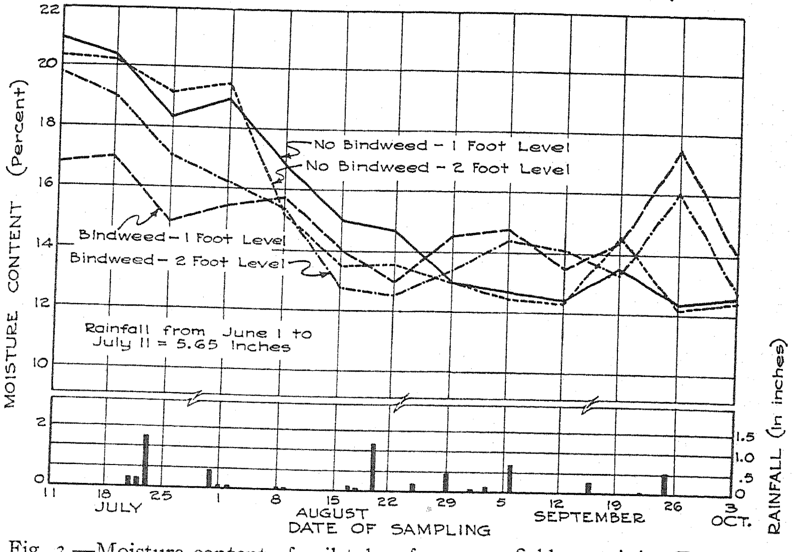

Fig. 3.—Moisture content of soil taken from corn field containing European bindweed and free from bindweed at 1- and 2-foot levels. Hawarden, Iowa. 1935.

was very little variation in the soil moisture at the 1- and 2-foot levels. The reading on July 11 showed the highest moisture content. From the middle of July until the latter part of August, the soil moisture content of the area free of bindweed was generally a little above that of the soil having the bindweed. From August 29 until the latter part of September the variations in the soil moistures were rather slight.

The month of June 1935 (11) was cool and wet with a total of 5.08 inches of rain. July, August, and September were hot and dry with deficient rainfall.

DISCUSSION

From the soil moisture data taken at 1- and 2-foot depths in areas containing the European bindweed and where no bindweed was present, the variation in the soil moisture was rather small. This situation was found to be present whether the soil moisture was above the wilting coefficient or near the wilting coefficient. The bindweed develops a deeply penetrating tap root but at the same time there are a large number of so-called feeding roots in the upper 2 feet of soil. So far, it has not been possible to determine the rate of water movement in the tap root, but no doubt it is of utmost importance in the water balance of the bindweed. The severing of the tap root under water

at a depth of 8 feet, with subsequent cutting of the feeding roots, did not lend itself to a study of the movement of water.

In an examination of the data and the graphs, it is rather significant that throughout much of the time during the years 1933, 1934, and 1935 the soil moisture was near the wilting coefficient. Breazeale (3) finds that a plant may absorb moisture from any soil horizon where water is available, for example a subsoil, and transport this moisture to another horizon where moisture is scarce. The available soil moisture is held by the soil with a force less than the suction force of the plant. The wilting coefficient is assumed to be the state of equilibrium which exists between the suction force of the plant and the adhesive force of the soil. According to Magistad and Breazeale (8) plants growing in soils above the wilting coefficient are able to absorb enough moisture to maintain turgor. As the soil moisture content decreases the rate of water absorption decreases, causing wilting to take place.

At permanent wilting, according to Bakke (1), considerable force is present. Conrad and Veihmeyer (7) have found that if a soil is wet at the beginning of a growing season to the full depth to which roots of the plants normally penetrate, subsequent additions of water by rain can have but little influence on the extent of the root system. Calling attention again to the rather small variation in the soil moisture content at depths of 1 and 2 feet, it would seem that there was additional evidence to support Briggs and Shanta (5) in their contention that all plants reduce the moisture to the same extent up to the attainment of permanent wilting. This relationship was also observed by Veihmeyer and Hendrickson (14) for sunflower plants.

Shantz (12) found that the point of exhaustion of available soil moisture may vary from a little below the wilting point to about one-half the amount under extreme desert conditions. Brezeale (3) maintains further that good crops of deciduous fruits may be produced in an orchard where the soil to a depth of several feet is kept at a little above the wilting percentage during a greater part of the growing season. He has observed that plants can absorb moisture from soils which are only slightly above the wilting coefficient quite as readily as they can from soils at the optimum moisture content. Veihmeyer (13) also studied the moisture relation of young prune trees and found that the rate of extraction of moisture by the trees was the same whether the moisture content of the soil is high or low. The intensity of the atmospheric evaporating environment seemed to govern the use of water.

The main absorptive roots of agricultural plants, according to Peterhänsel (10), is from roots at a depth of approximately 40 cms. The majority of the feeding roots according to Weaver, Jean, and Crist (15) are also in the upper 2 feet of soil surface, even though some of the roots may penetrate to a depth of 8 feet. From the standpoint of being able to extract more moisture from a given soil, there is apparently very little difference between corn and European bindweed.

Pavlychenko and Harrington (9) state that competition of cereals and weeds results in a reduction of the root development of cereals. The competition commences under the soil surface where the root systems compete for water and nutrients.

SUMMARY

Soil samples taken at depths of 1 and 2 feet from corn ground heavily infested with the European bindweed and from ground free of the weed during the summer months of 1933, 1934, and 1935 did not show marked differences in their soil moisture content.

The bindweed was able to maintain itself when the moisture content was below the wilting coefficient. The deeply penetrating root system was in all probability responsible for the action.

Corn does not compete successfully with the European bindweed when the soil moisture content is near the wilting coefficient. A 1-square-rod plat heavily infested with bindweed and planted to corn in 1933 and kept free of bindweed by weekly hoeing produced 33 pounds of corn while the control plat received three cultivations and produced 16 pounds of corn.

LITERATURE CITED

1. BAKKE, A. L. Determination of wilting. Bot. Gaz., 66:81–116. 1918.
2. ————. Experiments on the control of European bindweed (*Convolvulus arvensis* L.). Iowa Agr. Exp. Sta. Res. Bul. In press.
3. BREAZEALE, F. F. Maintenance of moisture equilibrium and nutrition of plants at or below the wilting percentage. Ariz. Agr. Exp. Sta. Tech. Bul. 29:137–177. 1930.
4. BRIGGS, LYMAN J., and SHANTZ, H. L. The wilting coefficient and its indirect determination. Bot. Gaz., 53:20–37. 1912.
5. ————, ————. The relative wilting coefficient for different plants. Bot. Gaz., 53:229–235. 1912.
6. CLEMENTS, FREDERIC E., WEAVER, JOHN E., and HANSON, HERBERT C. Plant competition. Carnegie Inst. Pub. 398. 1929.
7. CONRAD, J. P., and VEIHMEYER, F. J. Root development and soil moisture. Hilgardia, 4:113–134. 1929.
8. MAGISTAD, O. C., and BREAZEALE, J. F. Plant and soil relations at and below wilting percentage. Ariz. Agr. Exp. Sta. Tech. Bul. 25. 1929.
9. PAVLYCHENKO, T. K., and HARRINGTON, J. B. Root development of weeds and crops in competition under dry farming. Sci. Agr., 16:151–160. 1935.
10. PETERHÄNSEL, HEINRICH. Experimentelle Untersuchungen Über die Beziehungen zwischen Bodenfeuchtigkeit und Wassuverbrauch der Pflanzen. Bot. Archiv., 36:99–151. 1934.
11. REED, CHARLES D. Climatological data (Iowa Section in Cooperation with Iowa Weather and Crop Bureau). U. S. D. A. Weather Bur., 43, 1933; 44, 1934; 45, 1935.
12. SHANTZ, H. L. Drought resistance and soil moisture. Ecology, 8:145–157. 1927.
13. VEIHMEYER, Frank J. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia, 2:125–284. 1927.
14. VEIHMEYER, F. J., and HENDRICKSON, A. H. Soil moisture and permanent wilting of plants. Plant Phys., 3:355–357. 1928.
15. WEAVER, J. E., JEAN, FRANK C., and CRIST, J. W. Development and activities of roots of crop plants. Carnegie Inst. Pub. 316. 1922.

NOTES

A METHOD FOR CONTROLLING THE pH OF NUTRIENT SOLUTIONS IN STERILE SAND CULTURES[1]

THE apparatus described in this paper was devised for the purpose of studying the influence of pH on the nitrogen-fixing ability of certain Rhizobia. Difficulties were encountered in obtaining normal root growth, presumably because of lack of balance of the nutrients in the solutions used. The experiment has been discontinued temporarily, but in view of the fact that good pH control was attained under conditions that should make possible continuous sterile irrigation it is thought that a brief description of the apparatus may be of interest to others doing similar work.

A diagram of the apparatus is given in Fig. 1.[2] The nutrient solution was placed in the 40-liter carboy A and the Mariotte flask arrangement was used to maintain a constant head. From this carboy the solution moved through glass and rubber tubing to the 6-inch double-walled irrigator pot B.[3] The soil cavity of the irrigator pot was filled with well-washed white silica sand.[4] The porous cup C embedded in the sand was connected to the reduced pressure line D by means of glass and heavy-walled rubber tubing. A test tube sample trap was inserted in the outflow line at E.

The nutrient solution in the interwall cavity of the irrigator pot was usually at or slightly above atmospheric pressure. A partial vacuum pressure was maintained in the outflow line D and hence also in the porous cup. Under the action of this pressure differential the nutrient solution flowed from the porous inner wall of the pot, through the sand, out through the porous cup C and the brass drainage pipe D to the 40-liter containers F and G. The inclined brass drainage pipe D was 1 inch in diameter and 7 feet long and had spouts for attaching 14 of the pH control units. The nutrient solution for any pot, after passage through the sand, could be sampled for pH determination by clamping off the flow line on either side and substituting an empty test tube for E.

The porous cup was specially made to provide a 1¼ inch space at the sides and bottom for the quartz sand, this arrangement thus permitting approximately radial flow from the pot wall, through the sand, to the inner cup wall. A circular glass plate was placed in the bottom of each pot so as to cut off the moisture supply from the lower surfaces. This was done to keep the flow more nearly radial and to prevent excessive transfer of liquid through the sand at the lower levels

[1]Journal Paper No. J-619 Project 226, Iowa Agricultural Experiment Station, Ames, Iowa.

[2]The irrigator pots and porous cups were obtained from the General Ceramics Company, Refractories Division, New York City.

[3]RICHARDS, L. A., and RUSSELL, M. B. Apparatus for studying water relations in potted plants. Trans. Amer. Geophysical Union, 18th Ann. Meet., 588–592. 1937.

[4]The particle size distribution for the sand seemed to be well suited for the purpose and was as follows: 1.0–0.5 mm, 46.5%; 0.5–0.25 mm, 41.2%; 0.25–0.10 mm, 9.0%; 0.10–0.05 mm, 3.5%.

where the percentage saturation, and hence the moisture conductivity, is somewhat higher.

The vacuum pressure control panel is shown at the upper right in Fig. 1. The aspirator H was connected through the mercury air trap I in series with the bottles J and K to the mercury manometer L. Electric contacts in this manometer operated a solenoid valve in the

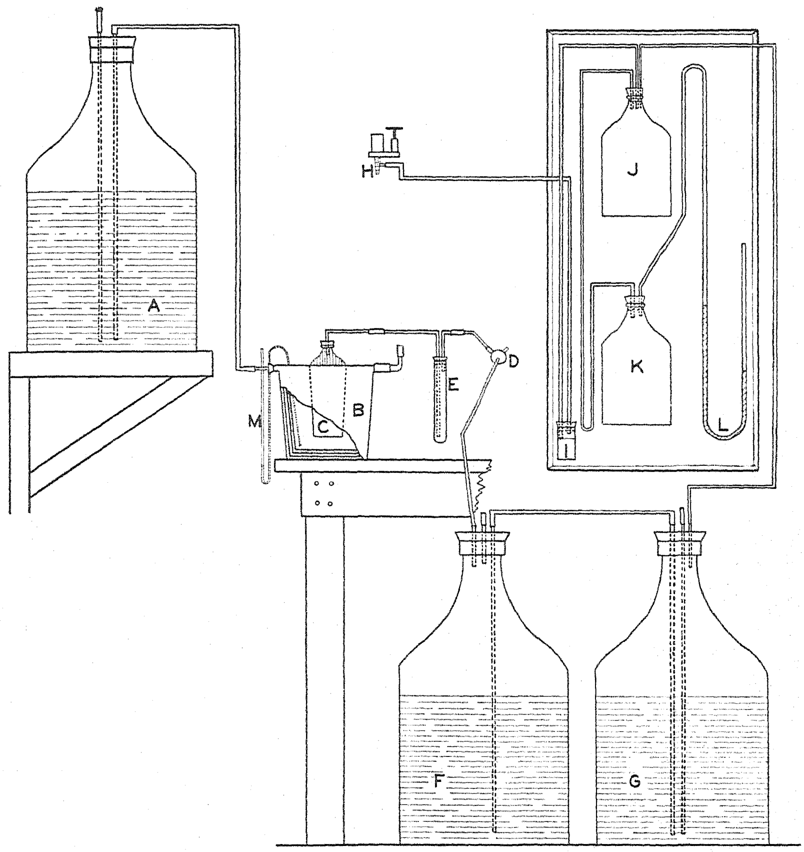

Fig. 1.—Arrangement of porous cells and carboys for controlling the pH of sterile nutrient solution in sand cultures.

water line to the aspirator. Resistance to air flow in the line connecting J and K allowed the aspirator to remove slightly more air than was necessary to open the electrical circuit in L, thus preventing continual turning on and off of the aspirator. A constriction near the bottom of the manometer tube effectively prevented oscillation of the mercury level.

Because of the influence of aeration it is desirable to have the percentage saturation of the nutrient solution in the quartz sand the

same in all the pots. As a check on this, glass U-tube manometers of the type shown at M were inserted in each pot. These manometers were filled with water and were plugged with cotton at the sand end. The level of the water in the open arm of a manometer indicates directly the pressure in the nutrient solution at the bottom of the sand column, the cotton plug making it possible to read negative as well as positive pressures. During the tests here reported the water table was kept at or slightly below the lower boundary of the quartz sand.

The porous cups at the centers of the pots were all connected to the same vacuum line. To balance out variations in the permeabilities of the various pot walls the heights of the supply reservoirs (A) were individually adjusted to bring the water table to the desired level in the sand.

It is evident that the liquid content of the quartz sand is determined by the balance between inflow and outflow. The effect of temperature on this balance, largely through the change in the viscosity, is shown in Fig. 2. The graph shows thermometer and manometer readings

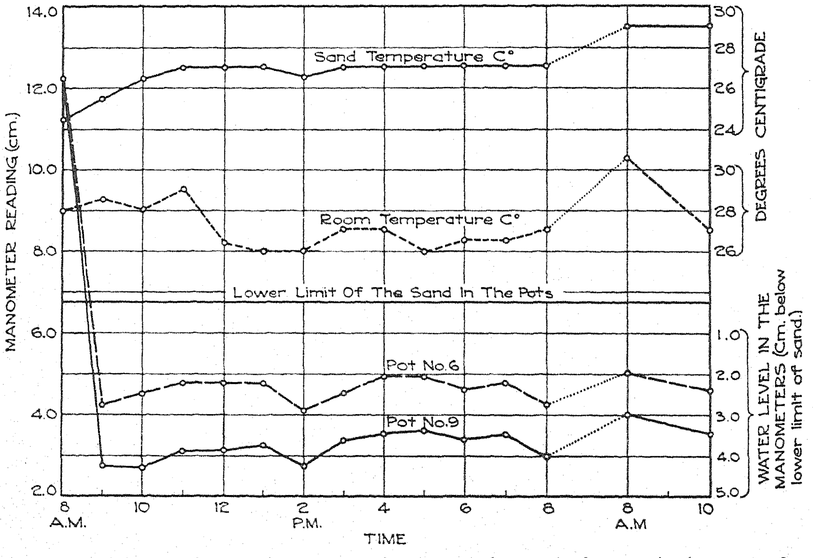

Fig. 2.—Fluctuation in the pressure in the nutrient solution at the bottom of the pot as related to the temperature changes.

plotted against time. As shown by the first two or three points on the graphs, equilibrium flow conditions were quickly established and rather stable.

The first solutions tested in the pots were buffered with tripotassium phosphate (K_3PO_4) and phosphoric acid (H_3PO_4) mixed in varying amounts. Sodium hydroxide (NaOH) was used for adjusting the pH. The phosphate solutions worked well at pH values of 7 or above but could not be used at lower values because of the steep slope of the buffering capacity curve below pH 5.4.

It was desired to have cultures varying in pH from 4 to 7. Based on the work of Tarr and Noble,[5] the next buffering agent tried was potassium acid phthalate [C_6H_4 (COOH) (COOK)]. The curve in Fig. 3

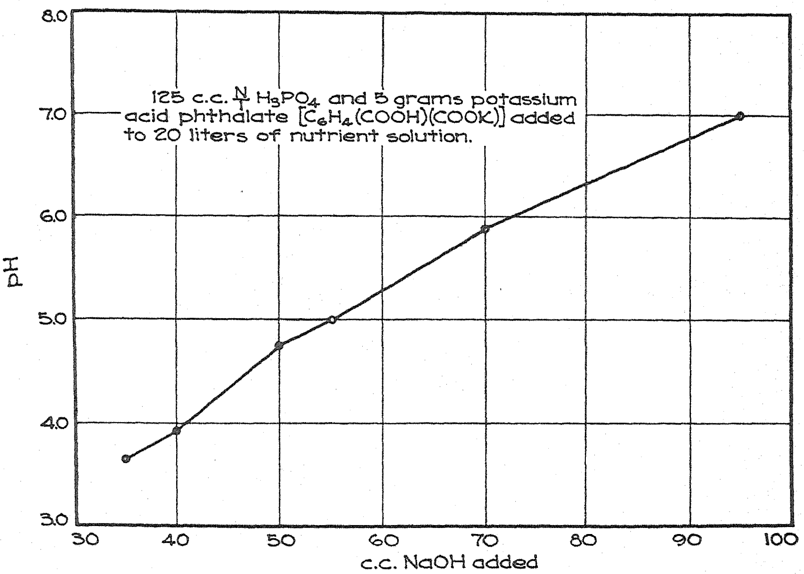

Fig. 3.—pH curve obtained by using [C_6H_4(COOH) (COOK)] as a buffer.

shows the relation between the pH and the amount of sodium hydroxide for this buffering agent and Table 1 gives a week's record of the pH of the solution after passage through the sand.

TABLE 1.—*The pH values of the original solution, O, before passage through the sand and the spent solution, S, after passage through the sand in which soybeans were growing.*

pH desired	Solution	Days						
		1	2	3	4	5	6	7
4.00	O	4.25	4.25	4.10	4.12	4.06	4.17	4.00
	S	4.30	4.34	4.34	4.31	4.26	4.20	4.07
5.00	O	5.16	5.16	5.14	5.14	5.13	4.95	4.95
	S	5.16	5.19	5.21	5.20	5.18	4.98	5.02
6.00	O	6.06	6.09	6.00	6.11	6.07	6.08	6.06
	S	6.11	6.13	6.12	6.15	6.11	6.08	6.13
7.00	O	7.07	6.95	6.95	7.04	7.02	6.98	7.07
	S	7.02	6.95	6.99	7.02	6.94	7.04	7.01

The precision of pH control, of course, is influenced somewhat by the rate of flow of the liquid through the sand. This rate may be

[5]TARR, L. W., and NOBLE, S. C. The effect of hydrogen-ion concentration upon the growth of seedlings. Del. Agr. Exp. Tech. Bul. 131. 1922.

varied by changing the vacuum pressure in the outflow line. For the data shown the flow rate was about 18 liters per day per pot. A particular advantage for the control system here described lies in the fact that the porous pot wall supplying the solution serves as a bacterial filter thus preventing the contamination of sterile cultures. Tests made in this laboratory by Dr. D. W. Thorne indicate that water from liquid cultures of three common rhizobia and also from a soil infusion was sterile after passage through an irrigator pot wall. Sterile conditions were obtained at the beginning of the experiment by autoclaving each irrigator pot with the sand, central cup, and water level manometer in place.—H. A. WILSON AND L. A. RICHARDS, *Iowa State College, Ames, Iowa.*

THE USE OF A TAYLOR PHOSPHATE SLIDE COMPARATOR FOR THE DETERMINATION OF PHOSPHATES IN SOIL EXTRACTS[1]

THE use of rapid chemical tests for determining available plant nutrients in soil has grown extensively during the past few years. Several different methods and extracting solutions have been used to remove the so-called available plant nutrients from the soil. Many of these methods employ the use of a porcelain spot plate for determining the amount of phosphorus in the soil extract. Due to the limitations of the spot plate method, a search was made for a more reliable method, rapid enough to fit in with the remainder of the soil testing procedure. The Taylor phosphate slide comparator (Fig. 1) seems to fulfill these requirements. The procedure consumes very little more time than the spot plate method, and the concentration of phosphorus can be determined to within 5 p.p.m. The method is a modification of the Farber and Youngburg[2] procedure for determining phosphates in waters.

REAGENTS

Molybdate solution.—Dissolve 50 grams of sodium molybdate (c.p.) in about 1 liter of distilled water. Filter, add 705 ml. of 10 N sulfuric acid, and then dilute to exactly 4 liters.

Concentrated stannous chloride.—Dissolve 16 grams of stannous chloride ($SnCl_2 \cdot 2H_2O$) (c. p.) in sufficient concentrated hydrochloric acid to make 100 ml. of solution. Allow to stand for a few hours for the stannous chloride to dissolve. This solution will keep indefinitely if stoppered tightly.

Dilute stannous chloride.—Dilute 2.5 ml. of the concentrated stannous chloride solution to 100 ml. with distilled water. This solution will not keep and must be freshly prepared every day.

PROCEDURE

Transfer 5 ml. of the soil extract to a 6-inch test tube, add 10 ml. of molybdate solution, 2.5 ml. of dilute stannous chloride, and mix well. A blue color will develop and its intensity will be proportional to the

[1]Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Agronomy.

[2]FARBER, J. E., and YOUNGBURG, G. E. Determination of phosphates in waters. Indus. & Eng. Chem., Anal. Ed., Jan. 15, 107. 1932.

amount of phosphate present. Maximum color develops rapidly, within a minute. On standing about 10 minutes, slow fading takes place, making it advisable to compare with the color standards within 10 minutes.

To make the reading, three of the five test tubes are placed in the holes back of the slots in the bottom of the base. The middle tube is filled with the blue solution resulting from the mixture of soil extract and reagents, while the other two tubes are filled with the soil extract. The slide containing the color standards is then placed in position on the base, and holding the instrument towards a window or other source of daylight (a colorimeter lamp was found to be a convenient

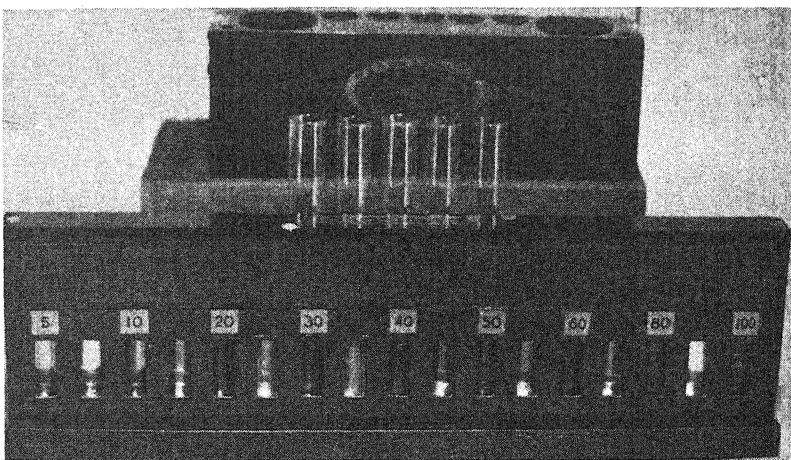

Fig. 1.—The Taylor phosphate slide comparator.

and constant source of light), the slide is moved back and forth until one of the color standards is found to match the unknown solution. When a color match is obtained, the concentration in parts per million is read directly from the values on the front of the slide. Since an average acre of soil to a depth of 6⅔ inches is considered to weigh 2,000,000 pounds the figures on the front of the slide can be multiplied by two and the amount of phosphate expressed as pounds per acre.

The chemicals used in making up the reagents and soil extracting solution should be as free as possible from phosphates and arsenates. If a blank run on the extracting solution contains more than 5 p.p.m. of phosphate, it is unsatisfactory. Caution should be exercised in making up and storing the reagents to prevent any contamination.

One of the chief disadvantages of the spot plate method is that frequently the soil extract is somewhat yellow in color. When the molybdenum blue color is developed in this yellow solution, the result is a greenish color which cannot be accurately compared with blue color standards. The Taylor comparator eliminates this source of error by placing a tube of the soil extract back of the color standards.

If the soil extract is colored, it changes the color of the standard so that it coincides very closely with the unknown solution. Another disadvantage of the spot plate method is that it is very difficult to reproduce on paper the exact shades of blue produced by the molybdenum blue reaction. As a result it is difficult to make accurate comparisons with a color chart even though the soil extract is colorless before the reagents are added. The Taylor comparator used liquid color standards and comparisons can be made within 5 p.p.m. with relatively little difficulty.

A modification of Morgan's universal soil testing system was used for the extraction.[3] Ten grams of air-dry soil which have been passed through a 2-mm screen and 20 ml. of Morgan's universal soil extracting solution are placed in a 50-ml. erlenmeyer flask, stoppered tightly, and shaken for 10 minutes. The mixture is then filtered and the filtrate tested for phosphorus and other plant food nutrients.

During the past 3 years the author has made some 6,000 phosphate determinations by this method and the results have been quite satisfactory. Almost all of the soil samples tested have been from soils being used for turf production, such as golf courses, parks, cemeteries, and lawns. About 1,800 of these samples were tested in a research project where more accurate results are necessary than for routine examinations. In both routine and research soil testing the color comparator has given satisfactory results.—T. C. LONGNECKER, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

BOOK REVIEWS

HUMUS: ORIGIN, CHEMICAL COMPOSITION, AND IMPORTANCE IN NATURE

By S. A. Waksman. Baltimore: Williams and Wilkins Co. Ed. 2. XIV+526 pages, illus. 1938. $6.50.

THIS edition appears less than three years since the first, and no very extensive changes have been made. Chapter VIII on "Humus Formation in Composts and Manures" has been enlarged by adding additional material on green-manuring and by adding a section on "Composting for Sanitary Purposes." At the end of the book a Chapter XVIII on "Humus and Soil Conservation" (eight pages) has been added.

In addition to these major changes, corrections have been made throughout and references to the most recent work have been inserted. The bibliography has been increased from 1,311 to 1,608 references. The entire book is 32 pages longer than the previous edition. (H.J.C.)

MANUAL OF SEDIMENTARY PETROGRAPHY

By W. C. Krumbein and F. J. Pettijohn. New York: D. Appleton-Century Co., Inc. XIV+549 pages, illus. 1938. $6.50.

THIS volume is a contribution by two members of the Department of Geology of the University of Chicago and is one of the Century Earth Science Series under the editorship of Kirtley F.

[3]MORGAN, M. F. The universal soil testing system. Conn. Agr. Exp. Sta. Bul. 372. 1935.

Mather. In the editor's preface Dr. Mather points out that the petrography of igneous rocks has been studied for well over half a century but that it is only within the past 20 years that any special attention has been paid to similar studies of sedimentary rocks. This new study, however, is not only extremely broad but may have considerable practical importance in such fields as physics, soil science, statistical method, and colloidal chemistry. In fact what has been done in this new field is to be found largely in the journals dealing with these four branches of science. This present volume brings together a complete treatment of the subject for the first time.

It is divided into two parts, the first by Dr. Krumbein dealing with sampling, preparation, mechanical, and statistical analyses and, the second by Dr. Pettijohn dealing with shape, mineralogical and chemical analyses, and mass properties.

The book is a highly technical treatment of the whole subject and should appeal to the pure research worker in this and allied fields. It touches the soil scientist at such points as analysis of sediments, including methods of dispersion, separation, size determination, statistical and graphical presentation, as well as identification through optical and other methods. Anyone interested in the mineralogical and geological origin of soils from sedimentary sources and in mechanical separation will undoubtedly find the manual very valuable. (R.C.C.)

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh: Oliver and Boyd. Ed. 7, XV+396 pages, illus. 1938. 15/.

THE preceding editions of this valuable and well-known work by Dr. Fisher have been reviewed in this JOURNAL so comparison with the last edition seems sufficient. The text has been increased by 13 pages, 12 of which are found in the additional section, 49.2, entitled "The Discrimination of Groups by Means of Multiple Measurements; Approximate Scores." This important new subject is discussed first by an outline of the development of the best discriminant functions with appropriate tests of significance and, second, by a numerical example and references to the wide variety of problems to which the method is applicable.

Section 27, "The Fitting of Curved Regression Lines," has been expanded by using orthogonal comparisons between observations to give a more extended introduction to the theory of orthogonal polynomials and to simplify the arithmetical work. Example 45 under "Technique of Plot Experimentation" has been amplified by the use of covariance in the analysis. In Section 30, a paragraph on errors in correlation analysis has been added. A few other changes and additions of minor importance also have been made.

One important change has been the omission of the duplicate, folded tables found at the end of the last edition. The number of sections, tables, and examples found in the 6th edition have not been changed. The press work maintains the high standard found in the other editions. (F. Z. H.)

PRINCIPLES OF GENETICS

By Edmund W. Sinnott and L. C. Dunn. New York: McGraw-Hill Book Co. Ed. 3. XIV+408 pages, illus. 1939. $3.50.

THE general outline and organization of the first edition has not been changed. Literature and problems follow each chapter. The third edition is 33 pages shorter than the second. (1932.)

Most changes affect the more advanced parts of the book which have been completely rewritten. The biometric methods by Charles, in the second edition, are replaced by a simplified treatment of biometrics in connection with multiple factor inheritance (Chapter VI) and the χ^2 method is incorporated in the fourth chapter. The entire evidence gained from salivary chromosome studies is new, and to add to the value of the book as a laboratory guide cultural directions are given in the appendix. A special chapter on inbreeding and heterosis, gene mutations, and chromosome changes will be of extreme value to the practical plant and animal breeder.

With excellent problems attached to each chapter, the present day student may be envied for having such ready access to a field touching on so many human endeavors. (B. R. N.)

HANDBOOK OF FERTILIZERS: THEIR SOURCES, MAKE-UP, EFFECTS AND USE

By A. F. Gustafson. New York: Orange Judd Publishing Co., Inc. Ed. 3. 172 pages, illus. 1939. $1.75.

THE first edition of this little volume was published in 1928; the second in 1932. This new edition is considerably enlarged, both by revision of older material and the addition of new. Like the former editions it is written primarily for the farmer and gardner who want to know more about the functions of the various fertilizer elements, their sources, combinations, crop responses, soil effects, and their purchase and practical use on various kinds of crops. It also includes latest information on home mixing, the use of lime, and crop responses to liming, and ends with a short chapter on organic matter.

For a short, concise, and practical treatment of these various phases of the subject, the book is worthy of a place in the working library of practical growers as well as of amateurs. It should also be found useful by teachers of agriculture. (R. C. C.)

AGRONOMIC AFFAIRS

PROGRAMS OF MEETINGS OF THIRD COMMISSION OF INTERNATIONAL SOCIETY OF SOIL SCIENCE AND OF SUBSECTION I, SECTION VIII, OF THIRD INTERNATIONAL CONGRESS FOR MICROBIOLOGY

THREE symposia dealing with different phases of Soil Microbiology will form the subjects of the meetings of the Third Commission of the International Society of Soil Science and of Subsection I, Section VIII, of the Third International Congress for Microbiology.

The meetings of the Third Commission will be held under the Presidency of Dr. H. G. Thornton of the Rothamsted Experimental Station, England, at New Brunswick, N. J., on August 30–31. These meetings will be followed by a one-day excursion in New Jersey. The meeting of Section VIII, of the Third International Congress for Microbiology, devoted to a discussion of the soil population, will be held on September 4 in New York City, under the Presidency of Prof. Orla-Jensen, President of Section VIII.

The preliminary program of these meetings is as follows:

Wednesday, August 30, 1–5 P.M.

Legumes and Legume Bacteria

1. A. I. Virtanen, Biochemical Institute, Helsinki, Finland—Symbiotic N-fixation by leguminous plants.
2. K. V. Thimann, Biological Laboratories, Harvard University, Cambridge, Mass., U. S. A.—The physiology of nodule formation.
3. R. Nilsson, G. Bjalfve, and D. Burström, Lantbrukshögskolan, Ultuna, Sweden—Growth factors for Rhizobia.
4. W. W. Umbreit and P. W. Wilson, Dept. of Agr. Bacteriology, Univ. of Wisconsin, Madison, Wis., U. S. A.—Studies on the mechanism of symbiotic nitrogen-fixation.
5. F. Allison, Bureau of Chemistry & Soils, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—Respiration rates of Rhizobium; their estimation and significance.
6. A. Demolon, Centre National de Recherches Agronomiques, Versailles, France—Bacteriophage and the growth of legumes (film).
7. H. Katznelson, N. J. Agr. Exp. Station, New Brunswick, N. J., U. S. A.—Bacteriophage and the legume bacteria.
8. H. G. Thornton, Rothamsted Experimental Station, Harpenden, England—Strains of nodule bacteria.
9. J. K. Wilson, Cornell University, Ithaca, N. Y., U. S. A.—Symbiotic promiscuity in the Leguminosa.
10. L. T. Leonard, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—Bacteria associated with *Gleditsia triocanthosy*.
11. P. L. Gainey and J. T. Kroulik, Kansas State Agr. College, Manhattan, Kansas, U. S. A.—The nitrogen fixing efficiency of *Rhizobium meliloti* endogenous to Kansas.
12. W. A. Albrecht, Univ. of Missouri, Columbia, Mo., U. S. A.—Some soil factors in nitrogen-fixation by legumes.
13. O. N. Allen, Univ. of Hawaii, Honolulu, Hawaii, U. S. A.—Rhizobium—leguminous plant relationships within the cowpea group.
14. A. L. Whiting, The Urbana Laboratories, Urbana, Ill., U. S. A.—Variations in the adaptability of strains of *Rhizobium leguminosarum*.

Thursday, August 31, 9 A.M.–12:30 P.M.

Microbiology of Soil Organic Matter

1. Ch. Barthel and N. Bengtsson, Lantbrukshögskolan, Ultuna, Sweden—The microbiological decomposition of the organic constituents of barnyard manure.
2. A. G. Norman, Iowa State College, Ames, Iowa, U. S. A.—
3. D. Burk, Bureau of Chemistry & Soils, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—The nature and extent of decomposition of Azotobacter cell nitrogen.
4. H. Murata, Kagoshima Imperial College of Agriculture & Forestry, Kagoshima, Japan—Ammonification of dicyanodiamide and its derivatives in soil.
5. C. E. Skinner, Univ. of Minnesota, Minneapolis, Minn., U. S. A.—Decomposition of amino acids by microorganisms.

6. M. F. MORGAN, Conn. Agr. Exp. Station, New Haven, Conn., U. S. A.—Some considerations in the maintenance of soil organic matter by green manures and cover crops.
7. S. C. VANDECAVEYE, Washington State College, Pullman, Wash., U. S. A.—Microbial activity in organic matter transformation in the soil.
8. F. E. CLARK and CHARLES THOM, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—Effects of organic matter soil amendments upon the microflora of the rhizosphere of wheat and cotton.
9. S. A. WAKSMAN, N. J. Agr. Exp. Station, New Brunswick, N. J., U. S. A.—The proximate method of analysis in the study of organic matter decomposition and of soil humus.
10. J. MARSZEWSKA ZIEMIECKA and J. GOLEMBIOWSKA, The National Institute for Agricultural Research, Pulawy, Poland—Cellulose decomposition in acid soils.
11. G. RUSCHMANN, Institut für Boden. und Pflanz., Landsberg a.d. Warthe, Germany—The use of new organic fertilizers.
12. D. FEHÉR, Institute of Forestry, Sopron, Hungary—Die Radioaktivität der Wüstenböden.
13. H. W. REUSZER, Colorado Agr. Exp. Station, Fort Collins, Colo., U. S. A.—The effect of benzoic acid compounds upon the abundance of microorganisms, including Azotobacter organisms, in a soil.
14. I. KRZEMIENIEWSKI, Institut de Botanique et Biologie, Leopol, Poland—

THURSDAY, 1:30 P.M.–4:00 P.M.

Discussion of Legume program. Prof. E. B. Fred, in charge.
Discussion of Organic Matter program. Dr. Charles Thom, in charge.

THURSDAY, 4:00 P.M.

Conference on Legume Inoculants, Dr. A. W. Hofer, in charge. Anyone interested will please correspond with Dr. Hofer, N. Y. Agr. Exp. Station, Geneva, New York.

FRIDAY, SEPTEMBER 1

Morning.—Visits to Rockefeller Institute, Princeton University and Walker-Gordon Dairy.

Afternoon.—Visits to Nematode Control Laboratory, Cranberry Substation and Salt Marshes.

MONDAY, SEPTEMBER 4, 9 A.M.–1 P.M.

Meeting of Subsection I, Section VIII, of the Third International Congress for Microbiology, Waldorf-Astoria Hotel, New York City.

THE SOIL POPULATION

1. H. J. CONN, N. Y. Agr. Exp. Station, Geneva, N. Y., U. S. A.—The autochtonous flora of the soil.
2. R. L. STARKEY, N. J. Agr. Exp. Station, New Brunswick, N. J., U. S. A.—Influence of plants upon the soil population.
3. A. G. LOCHHEAD, Central Experimental Farm, Ottawa, Canada—The soil population.
4. C. STAPP, Biolog. Reichsanst. f. Land. und Forstwirtschaft, Berlin-Dahlem, Germany—Über Begleitorganismen der Nitrifikations—Bakterien.
5. D. FEHÉR, Kgl. Ung. Palatin Josef Universität, Sopron, Hungary—Die komplexe Wirkung der Bodentemperatur und der Bodenfeuchtigkeit als regulative Grundfaktoren des Bodenlebens.
6. I. L. BALDWIN, Univ. of Wisconsin, Madison, Wis., U. S. A.—Rhizobia in relation to the general soil population.
7. A. Niethammer, Univ. of Praha, Praha, Czechoslovakia.—Die Pilzflora der Samen und Früchte unter Hervorhebung ihrer Bedeutung für die Entwicklung der Keimlinge.

8. Jan Smit, Landbouwhoogeschool, Wageningen, Holland.—The relationship of copper to the development of soil microorganisms.
9. T. Gibson, Edinburgh and East of Scotland College of Agriculture, Edinburgh, Scotland—The bacterial flora characteristic of soils.
10. P. H. H. Gray, Macdonald College, Quebec, Canada—
11. K. T. Wieringa, Landbouwhoogeschool, Wageningen, Holland—The ratio of actinomyces to other microorganisms in the soil especially in connection with the appearance of potato scab.
12. Vaclav Kas, Institut agropedologique de l'Etat, Prague, Czechoslovakia—Microbiological characteristics of the climatological soil types.
13. M. Winnik, Agricultural School, Mikveh-Israel, Palestine—The seasonal changes in bacterial numbers and activities in some Palestinian soils.
14. N. James, University of Manitoba, Winnipeg, Canada—The errors of the plating method.
15. J. E. Greaves, Utah Agr. College, Logan, Utah—Some factors influencing nitrogen fixation.
16. Y. Ziemiecka, National Institute for Agricultural Research, Pulawy, Poland—The influence of different treatments on the soil population.
17. T. L. Martin, Brigham Young Univ., Provo, Utah, U. S. A.—The algal population of the soil.
18. H. A. Barker, Univ. of California, Berkeley, Calif., U. S. A.—The nature and distribution of methane-producing bacteria.

Discussion of program. Sir John Russell, in charge.

For reservations, accommodations, and general information pertaining to the meetings of the Third Commission in New Brunswick (August 30 to September 1), communicate with Dr. R. L. Starkey, New Jersey Agricultural Experiment Station, New Brunswick, N. J., in charge of Local Committee on arrangements. For reservations and general information pertaining to the Microbiological Congress in New York (September 2 to 9), communicate with Dr. M. H. Dawson, College of Physicians & Surgeons, 620 West 168th Street, New York City, General Secretary of the Congress.

KORSMO'S WEED PLATES

THE third set of Professor E. Korsmo's weed plates, Nos. 59–90, are now available through Koehler & Volckmar A.-G. & Company, Leipzig, Germany. These multicolored plates, representing 138 species of weeds (84×64 cms.), show the important stages in their development. In this last set are such common weeds as *Lepidium draba*, *Agropyrum repens* (L.) P.B. No. 85, and *Circium lanccolatum* (L.) Hill. The quoted price is RM 49.

COMBINED SUMMER MEETINGS OF THE CORN BELT AND NORTHEASTERN SECTIONS OF THE SOCIETY

PRELIMINARY announcement of the combined summer meeting of the Corn Belt and Northeastern Section of the Society to be held in Ohio, June 14, 15, and 16, has been supplied by Dr. L. D. Baver, Department of Agronomy, Ohio State University, Columbus, Ohio, from whom further details may be obtained.

WEDNESDAY, JUNE 14, COLUMBUS

9:00 A.M.	Registration at Columbus.
9:30 A.M.	Inspection of soils and crops experiments.

12:30 P.M. Box lunch on University Golf Course.
2:00 P.M. Leave golf course for Wooster.
7:30 P.M. Discussion groups at Wooster.

1. Organization of agronomic research in Ohio, and major soil differences and types of farming.
2. Group discussions on research problems in soil fertility, soil biology, soil conservation, forages and pastures, corn, small grains, soybeans, and turfs.
3. Group discussion on the coordination of research and extension in Ohio.

THURSDAY, JUNE 15, WOOSTER

8:30–11:30 A.M. Detailed inspection of certain soils and crops experiments by special interest groups, including forages, pastures, grains, and fertility.
1:00– 5:00 P.M. Inspection of experiments of general interest in addition to those not visited in the morning by a given group.
7:00 P.M. Annual banquet.

FRIDAY, JUNE 16

(All tours and conferences optional)

1. Tour to hydrologic and climatologic projects at Coshocton and New Philadelphia in southeastern Ohio.
2. Tour to Trumbull County Experiment Farm in Northeastern Ohio.
3. Tour to Northwest Experiment Farm (heavy clay land) near Indiana line.
4. Soft wheat breeder's conference at Wooster.
5. Grassland conference at Wooster.

SUMMER MEETING OF SOUTHERN SECTION

THE summer meeting of the Southern Section of the Society will be held in Mississippi August 1, 2, 3, and 4, 1939. Although the details of the program have not been worked out, plans include a study of the cotton breeding and ginning, soil fertility, forage and pasture investigations, and potato starch production. An automobile trip through the state is planned which will take the party to certain of the branch stations and through different soil areas of the state.

MEETING OF WESTERN BRANCH

THE Western Branch of the American Society of Agronomy will meet on the Davis campus of the University of California on June 6 for a tour of crops and soils experiments; and then move to the cooler environs of the Berkeley campus for formal meetings on June 7 and 8. Agronomists outside the region are also invited. Those desiring to present papers or wanting further details should communicate with Mr. Coit A. Suneson, Secretary of the Western Branch, University Farm, Davis, California.

JOURNAL
OF THE
American Society of Agronomy

Vol. 31 May, 1939 No. 5

THE GEOGRAPHICAL DISTRIBUTION OF SOIL BLACK PIGMENT[1]

W. Sherman Gillam[2]

A STUDY of black pigment in soil necessarily involves, to a minor degree, a study of soil humus. These organic fractions are intimately associated with soil genesis, and their importance in characterizing a soil and the significant rôle they play in soil-forming processes, are well recognized. A great number of ideas have been propounded concerning the nature of soil humus but little is definitely known about its true chemical nature.

Similarly, very little is known about the geographic distribution of the black pigment, for apparently no investigation has been completed along this line. Related work that has been published deals with the distribution of nitrogen or organic matter. These latter two, of course, are very closely associated since they bear a fairly constant ratio to each other. However, it does not necessarily follow that organic matter content and pigment content of a soil have any such relationship.

A few authors hold that in red soils, or soils in the subtropical and tropical regions, no dark-colored humus fraction exists, while other investigators maintain that the colored organic fraction is present but its presence is masked by various hydrated oxides.

A study of the chemical nature of soil black pigment was made in this laboratory (4).[3] That fraction of the soil organic matter peptized by 4% ammonia, precipitated by acids, and insoluble in 95% ethanol was designated as the soil black pigment. Various pigment fractions, although isolated from soils in different soil groups, were found to be remarkably consistent in chemical and physical properties, which indicated that the same central nucleus was present in each pigment. For the extraction of these pigments, samples from many soil types were used. This afforded an opportunity for comparing the pigment content of various soil groups, for studying its geographical distribution, and for correlating it with climate.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director as paper No. 220, Journal Series, Nebraska Agricultural Experiment Station. Received for publication December 5, 1938.

[2]Instructor.

[3]Figures in parenthesis refer to "Literature Cited", p. 387.

The formation of soil pigment and soil organic matter is a function of such factors as climate, vegetation, biological activities, topography, and drainage. Since we do not know which of the above-mentioned factors exerts the greatest influence upon pigment formation, it was necessary to limit the study to those factors for which we have definite values. The other factors we must assume remain constant. Of these five factors probably the most important are climate, vegetation, and biological activities. Our knowledge concerning the microbiological activity in the various soil regions is very meager. The influence of vegetation can be noted in a very general manner, but practically all of the soils studied in this investigation were from a grassland region. On the other hand, we have rather extensive data dealing with the climate of different areas.

The important climatic factors are temperature, precipitation, and evaporation. The latter two are generally combined into a single quotient called the humidity factor. The correlation of black pigment and climate was therefore limited to the influence of temperature, precipitation, and, where possible, to the humidity factor.

THE SOIL SAMPLES

The soils employed in this study were in part taken from the collection of the Agronomy Department of the Nebraska Agricultural Experiment Station and in part were collected for the specific purposes of this investigation. The methods of collection were consistent throughout. All samples were from virgin areas, either meadows or clean roadsides, or in a few cases virgin forests. Generally, they were composites of ten and always three or more cores in a location, these being spaced in a 50 to 100 yard line over a uniform virgin expanse. As a rule, samples were taken with special tubes, but in rare instances a graduated spade was used. Vegetation and surface debris were always removed before sampling, but in preparing the samples for analysis, roots, rhizomes, etc., were never discarded.

Over 300 samples were used in this investigation. Recognizing that in the prairies (8) horizonation of organic matter is not distinctly manifest in the upper foot, all the soils were sampled to an empirical depth, namely, by two 6-inch sections. For this study only the 0 to 6-inch samples were used except in some minor comparisons. The air-dried samples were ground to pass a 1-mm sieve or finer as required for the various determinations of hygroscopic moisture, hygroscopic coefficient, or organic matter and humus extracts.

The location of all samples used are shown in Figs. 1 and 2. Fig. 1 shows the distribution of samples in Nebraska and correlations with rainfall and temperature. Fig. 2, with a few exceptions, shows the geographic distribution of all samples.[4]

[4]All the samples of North Dakota and several of those in South Dakota were collected for the author by Dr. F. A. Hayes of the Bureau of Chemistry and Soils. Other South Dakota samples were collected by J. C. Russel of the Agronomy Department as were also all of the Wyoming and a few of the Kansas samples. A few of the Colorado samples were collected for the author by Dr. L. A. Brown of the Colorado State College. Several additional samples from Michigan, not shown by the map, were furnished through J. O. Veatch of the Michigan State College and Dr. M. D. Weldon of the Nebraska Agronomy Department. Several others from North Carolina were furnished by C. B. Clevenger, North Carolina State College. The Nipe sample from Cuba was furnished by Ray C. Roberts of the Bureau of Chemistry and Soils. All other samples, inclusive of those of Kansas,

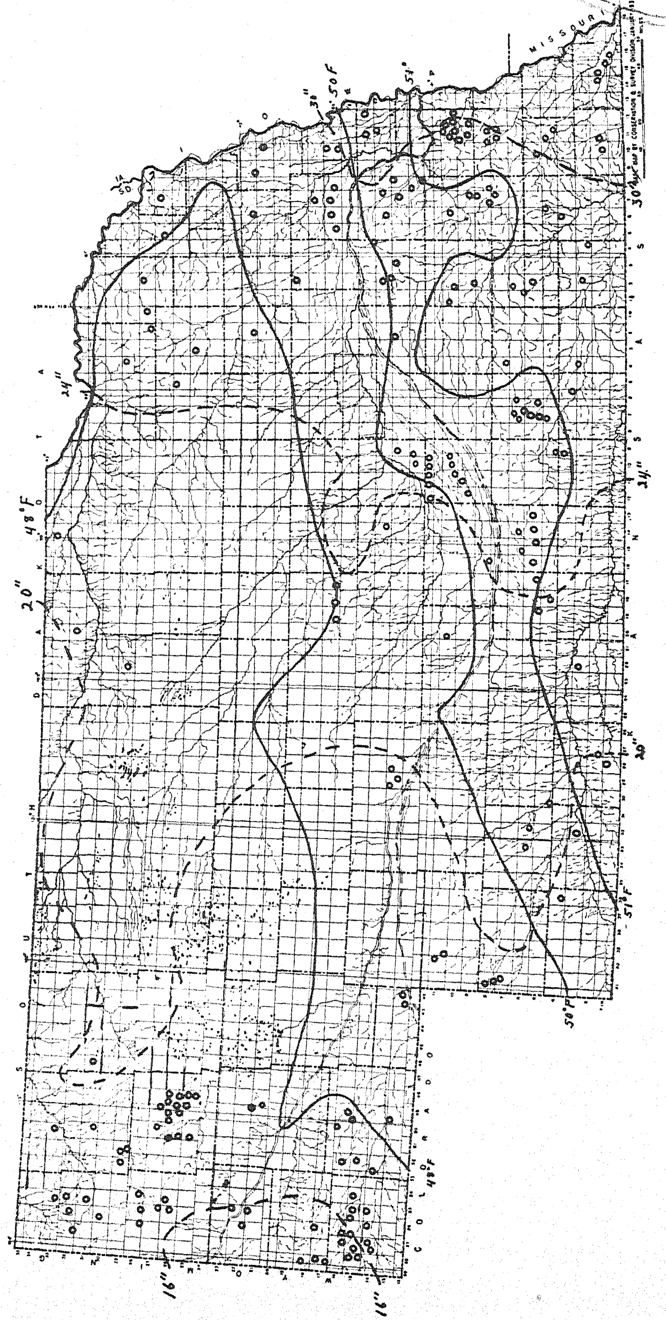

FIG. 1.—Location of all soil samples in Nebraska. Broken lines indicate mean annual precipitation; solid lines mean annual temperature; and each small circle a composite of 10 or more cores.

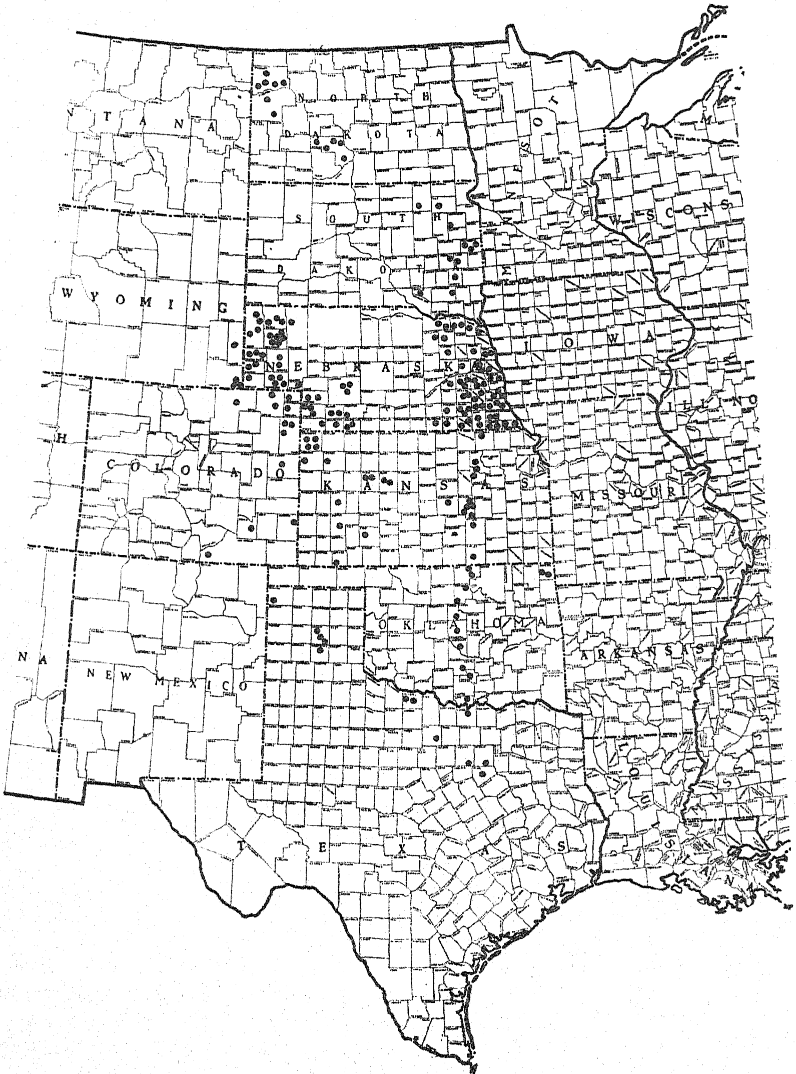

FIG 2.—Distribution of most of the soil samples over the Great Plains area. Each black dot represents a composite of 5 to 10 cores.

DETERMINATION OF PIGMENT CONTENT

The quantitative extraction of soil pigment by means of dilute ammonia or sodium hydroxide is next to impossible. The author, working with samples of muck, has extracted a single sample as many 20 times over a period of two weeks without obtaining any quantitative separation of the pigment.

Oklahoma, Texas, and Colorado, were collected by the author specifically for this subject. Grateful acknowledgment is hereby extended to all those who assisted in the gathering of samples either at the author's request or otherwise.

Thus, an indirect method had to be used for determining the relative amount of soil black pigment present in various soil samples. For this purpose, recourse was had to the colorimetric method, since various workers (1, 2, 3, 11) have concluded that it is sound in principle. However, this method has been subjected to considerable criticism. Probably the most logical explanation for its limitations was pointed out by Gortner (5). In this investigation no attempt was made to calculate the amount of humus present in the soil samples by the colorimetric method. Instead, the relative percentage of humus was determined gravimetrically.

In general, soil organic matter may be considered as consisting principally of two fractions (5); one portion consists of colorless or very slightly colored substances, while the other fraction is highly colored. Therefore, if the ammoniacal extracts of various soil samples were diluted until they contained equal amounts of humus, as determined gravimetrically, and were then compared colorimetrically against some color standard, one could obtain a measure of the relative humus color and the relative pigment content of the different extracts. Thus the relative humus color of the various extracts is simply the ratio of $\frac{\text{standard reading} \times 100,}{\text{reading of extract being examined}}$, whereas the relative pigment content was obtained by multiplying the relative humus color by $\frac{\text{\% humus in extract being studied.}}{\text{\% humus in standard}}$ This affords a relative method for studying the distribution of the black pigment.

The colorimeter used was a Campbell-Hurley. It consists primarily of two glass cylinders, one of which contains a column of liquid of a definite depth, while the depth of the standard solution in the other cylinder is varied at will by a mechanical method. For illumination, north daylight was used.

PREPARATION OF THE STANDARD SOLUTION

The standard solution used in all colorimetric determinations was obtained from a Barnes silt loam soil of McCook County, South Dakota. This soil had an organic matter content of 5.22% and a humus content of 1.88%. The equivalent of 50 grams of the oven-dry soil was mixed with an equal weight of clean quartz sand and placed in a percolation tube (9). It was then leached with 1% hydrochloric acid until no test for calcium could be obtained in the leachate. Following this, distilled water saturated with carbon dioxide was passed through the soil column until no test for chloride was obtained in the leachate. Finally a solution consisting of 4% ammonia and 2% ammonium carbonate was percolated through the soil and exactly 1,200 cc of the jet black solution collected. Fifty cc of the extract contained 0.0392 gram of ash-free humus, equivalent to 1.88%. Two hundred cc of the extract were then diluted with 4% ammonia to 1,568 cc, thus reducing the humus content to 100 p.p.m., or 1 part of humus to 10,000 parts of solution. This was the standard solution, containing 100 p.p.m. of humus, that was used in the colorimeter. Consequently, the humus content of any extract, in p.p.m. of solution, in p.p.m. of soil, or the grams of humus leached out of the soil sample, could be readily calculated.

METHOD OF EXTRACTION

The procedure used in the preparation of the color standard was likewise used in the extraction of the humus solution from the soil samples. The acid leachate in all cases was pale yellow in color, except for the forest soils where it acquired

a more reddish tint. Each sample was run in duplicate. The ammonia solution was fed to the percolating tube through ground glass tips calibrated to deliver 1.5 cc per minute. Thus, each sample was in contact with the extracting solution for approximately the same length of time.

The relative percentage of humus extracted and its ash content were determined gravimetrically for every sample. Finally an aliquot of each ammoniacal extract was withdrawn, diluted until it contained 100 parts of humus per million of solution, and compared in the colorimeter against the standard. The relative humus color and pigment content were calculated from these readings.

The extracts from several of the samples were collected in 300-cc portions, aliquots withdrawn, diluted, and read in the colorimeter. Parts of humus per million of solution were calculated and plotted against volume of the extract in cc. Five samples chosen at random are shown in Fig. 3.

These curves showing parts per million of humus plotted against volume of extract in a general way fall about as one would surmise. The first 300-cc portions of the ammoniacal extracts from the Kansas samples have a much higher content of humus than do the samples from southern Oklahoma. The northern soils therefore require a slightly larger volume of solution before the extracts become colorless or very faintly colored.

The ammoniacal leachate of practically every sample was very nearly colorless after 600 cc of solution had percolated through the soil column. This is illustrated by the curves in Fig. 3. Consequently, with many samples, only 800 cc of solution were percolated through the tube.

ORGANIC MATTER AND HUMUS DETERMINATION

The organic matter content of all soil samples was determined by the hydrogen peroxide method (7). All samples were run in duplicate and made to check within 0.2%. Most of them checked within 0.1%. Samples having a high content of carbonate were treated with dilute acid to remove the carbonate, and the organic matter was determined on the portion remaining.

To determine the relative humus content, a sample of the ammoniacal extract was evaporated to dryness in a platinum dish, weighed, ignited, and weighed again. From this difference in weight, the relative percentage humus was calculated.

INCUBATIONS

In order to determined whether the relative pigment content, or humus color, could be increased by the addition of organic matter to a soil or sand medium, the following experiment was performed:

The equivalent of 15 grams of oven-dry organic matter and 285 grams of oven-dry Rosebud silt loam soil were placed in each of seven 1-pint milk bottles and thoroughly shaken. Sufficient distilled water was then added to bring the water content up to the moisture equivalent of the soil. The bottles were then capped with cheesecloth, weighed, and placed in a constant temperature room. The weight of each bottle was kept constant by frequent additions of distilled water.

Three organic materials were used in a soil medium, sand medium, and in a sand medium inoculated with water leached through a Marshall surface soil. The following organic materials were used:

Wheat straw	0.42 % N	7.4 % H_2O
Horse manure	1.35 % N	7.5 % H_2O
Alfalfa hay	2.69 % N	7.9 % H_2O

These composts were sampled immediately after mixing and at intervals of 4, 8, 16, 32, 44, and 62 weeks. The percentage of moisture was determined on each sample and the equivalent of 50 grams of oven-dry material was placed in perco-

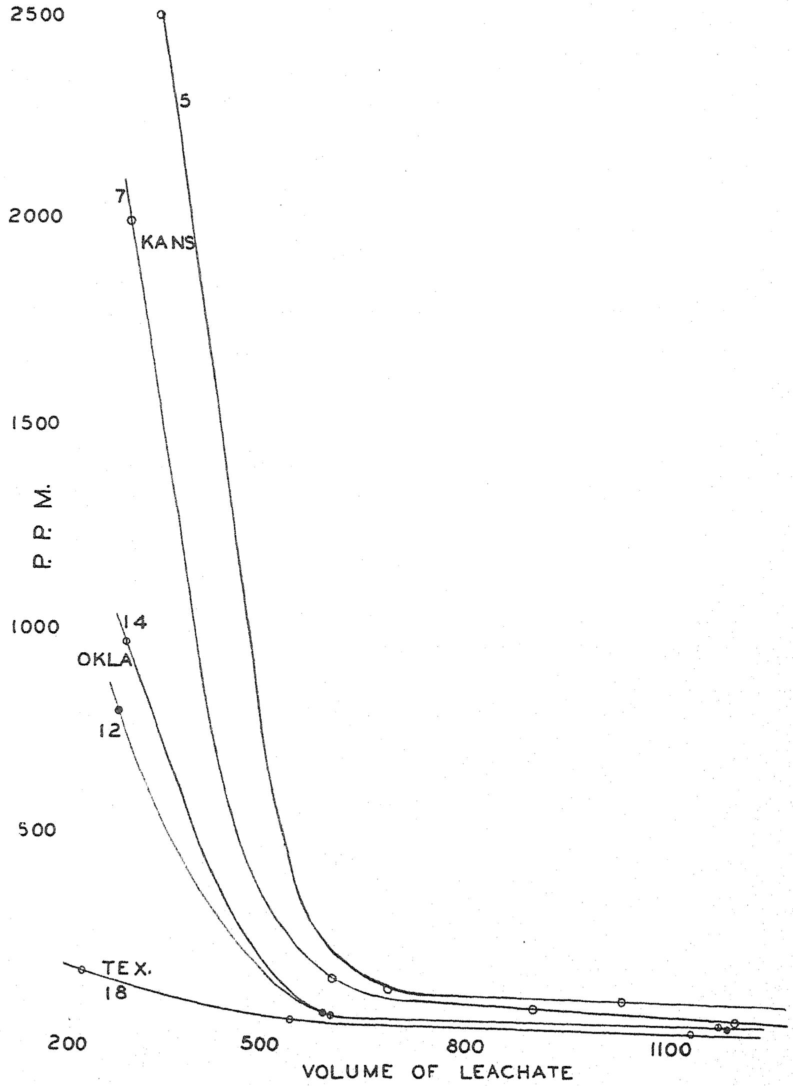

FIG. 3.—Relationship between volume of leachate and humus concentration. Curves 5 and 7, 12 and 14, and 18 illustrate this relationship for soils from Kansas, Oklahoma, and Texas, respectively.

lation tubes and leached exactly as the soil samples were leached. The percentage of humus was determined gravimetrically and the extracts compared against the same standard in the colorimeter.

The results showed that addition of organic materials to the soil and sand mediums slightly increased the percentage of ammonia-soluble material of the samples. Alfalfa and horse manure increased this more than the straw. The percentage of ammonia-soluble material, however, did not increase with age and the relative humus color and relative pigment content of the soil likewise were not increased over the 12-month period.

The samples moistened with soil water appeared darker in the colorimeter than those containing only distilled water, but there were insufficient samples to warrant any conclusion being made.

Extracts from the sand medium did not match the color standard, especially in the early part of the incubation period. The solutions were somewhat green or greenish-yellow in comparison to the standard. Toward the end of the period the extracts did become darker colored and matched the standard more closely.

DISCUSSION

In a study involving comparisons of the black pigment in different soils the samples used should possess approximately the same texture. Furthermore, all samples should be from normally developed well-drained soils of the uplands. Consequently, no samples were used from soils developed on a terrace or first bottom. In selecting the soil samples it was not expedient to obtain samples of equivalent texture, therefore the hygroscopic coefficient was used as an expression of texture (10). All samples can then easily be placed on an equivalent basis, and consequently the influence of any factors, which ordinarily would be completely overshadowed by differences in texture, can be illustrated.

Each point in Figs. 4 to 7 and 9 to 10 represents the average of many samples reduced to a uniform textural basis equivalent to a hygroscopic coefficient of 10. All the curves are drawn so that the sum of the squares of the deviations of all points is at a minimum. The data from which these curves were plotted are listed in the appendix of the thesis (4).

PIGMENT TEMPERATURE RELATIONSHIP

In order to study the variation of the soil black pigment with temperature, humidity factors must be kept constant. N.S. quotients were calculated where sufficient data were given for every weather station within the area. The range in N.S. quotients for the entire region was 125 to 260. The area, therefore, is classed as a semi-arid region since the N.S. quotients closely approach the 125–250 range set by Jenny (6). The data plotted in Figs. 4 and 5 were obtained from samples collected, so far as possible, along an isohyet from South Dakota to Texas (Fig. 2). The N.S. quotients along this eastern line range from 140 to 260.

The two curves in Fig. 4 are sigmoidal and illustrate the distribution of soil organic matter and humus with changing temperature. As the temperature increases from around 43° to 55° F both the percentage of organic matter and the humus decrease only slightly. However, from 55° to approximately 61° F the rate of decrease of organic matter and soil humus is at a maximum. The curves represent a spread

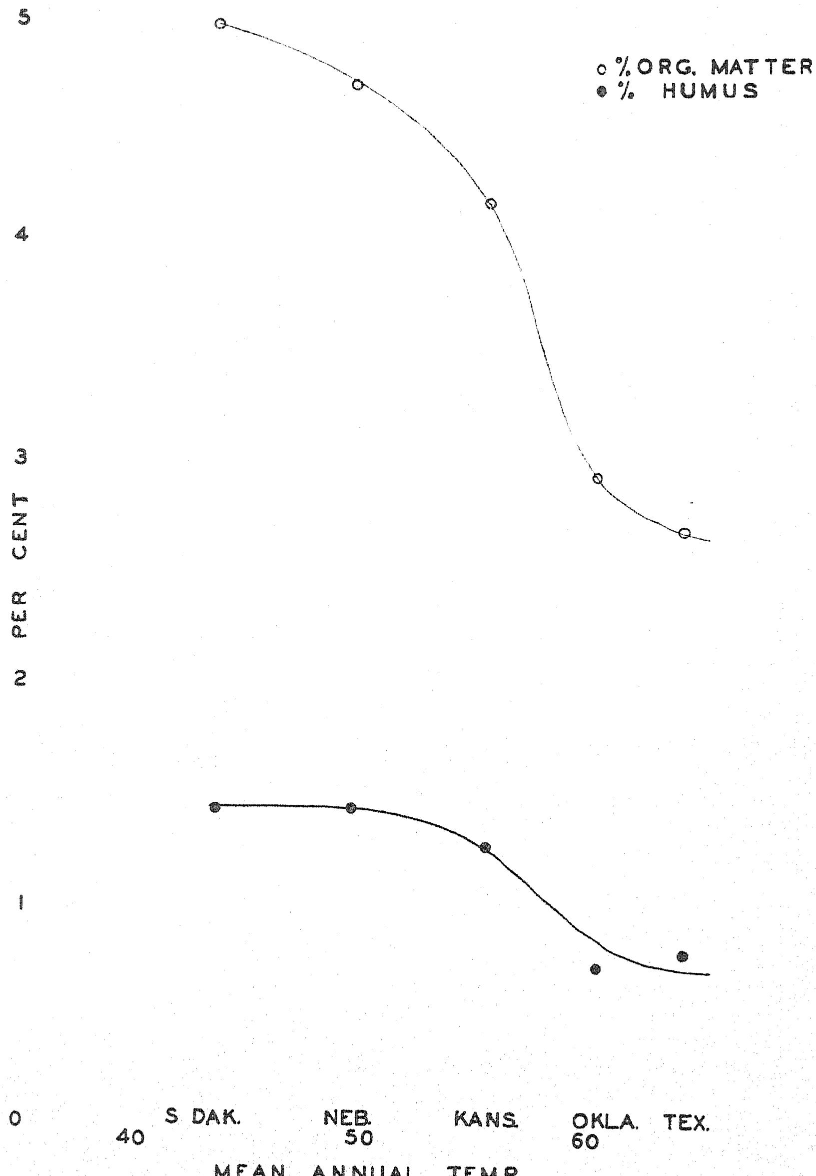

FIG. 4.—Relationship between mean annual temperature and the relative humus content and organic matter content where the mean annual precipitation is approximately 29 inches. Each point in figures 4 to 7, 9, and 10 represents the average of many samples reduced to a uniform textural basis equivalent to a hygroscopic coefficient of 10.

of approximately 18° F, or 10° C, and illustrate the fact that for a fall of 18° F in mean annual temperature the average soil organic matter and humus content are about doubled.

Fig. 5 brings out the linear relationships of both relative humus color and relative pigment content to temperature. Furthermore, for an 18° F drop in mean annual temperature the relative pigment content of the soil has been increased five or six times, while the relative humus color has increased approximately three times.

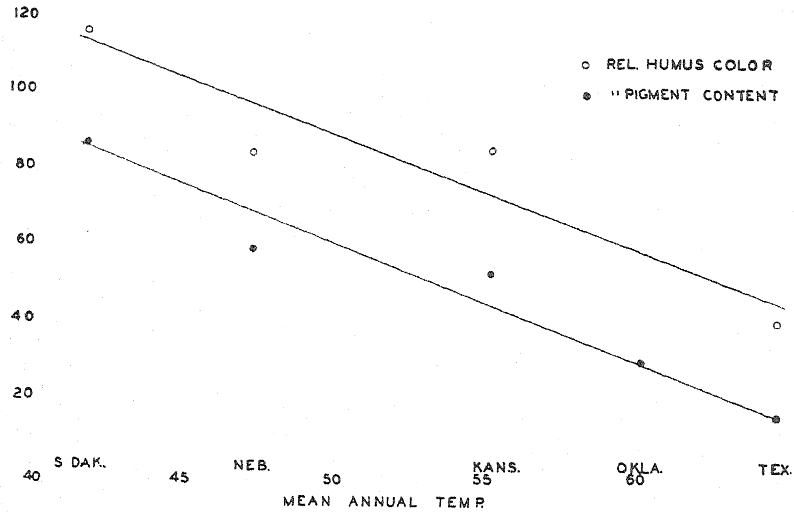

FIG. 5.—Relationship between mean annual temperature and the relative pigment content and relative humus color where the mean annual precipitation is approximately 29 inches.

The data plotted in Figs. 6 and 7 were obtained from samples lying on an isohyet line to the west of those plotted in Figs. 4 and 5 (Fig. 2). Consequently, we would expect somewhat lower organic matter, humus, and pigment contents than were obtained in the former series of samples. Again we note that the curve for the percentage of organic matter is sigmoidal. The points on the humus curve are possibly too widely scattered to allow any similar conclusions to be drawn.

In this area a drop of 18° F in mean annual temperature has increased the organic matter content only 1.5 times. The curves in Figs. 4 and 6 indicate that the influence of temperature on the organic matter, humus, and pigment contents is slightly greater in the region of higher rainfall than it is in the region of lower rainfall.

Again, in Fig. 7, the parallelism between humus color and pigment content is brought out. Similarly, there is a linear relationship between humus color, pigment content, and mean annual temperature. For an 18° F drop in mean annual temperature the relative pigment content has increased two to two and one-half times and the relative humus color about two to three times. The increase in relative pigment content is much less for this region than for that of the more eastern area.

The correlation between pigment content and rainfall was studied over a relatively small area. The soils investigated lie along an isotherm from eastern Nebraska into eastern Wyoming and Colorado.

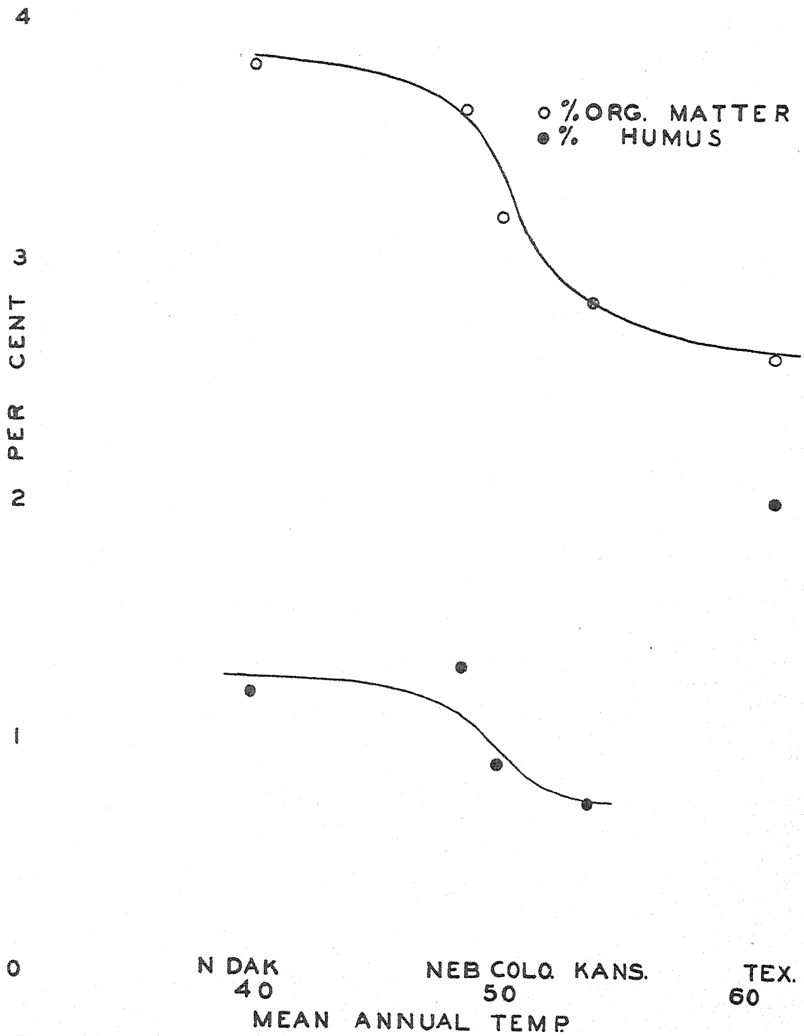

FIG. 6.—Relationship between mean annual temperature and the relative humus content and organic matter content where the mean annual precipitation is approximately 18 inches.

The location of the samples in Nebraska is primarily between the 48° F and 50° F isotherms, continuing on into Colorado and Wyoming (Fig. 1). The samples were divided into three groups as follows: Group 1 consisted of those lying east of the 24″ isohyetal line, group 2 those lying between the 20″ and 24″ lines, and group 3, composed

of samples lying west of the 20" isohyet. In two instances a fourth group was added, consisting of samples in Wyoming and central Colorado.

The results reduced to an equivalent textural basis of H. C = 10, are plotted in Figs. 9 and 10. Groups 1 and 3 are very well represented by soil samples, but group 2 contains a much smaller number. However, this group contains three samples which are composites of five fields each, and the data may therefore be more reliable than is apparent.

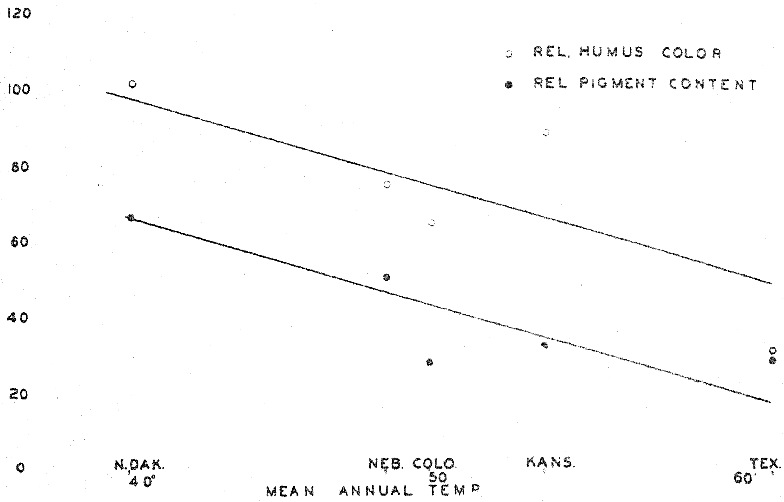

FIG. 7.—Relationship between mean annual temperature and the relative pigment content and relative humus color where the mean annual precipitation is approximately 18 inches.

When the organic matter content of soils is plotted against mean annual precipitation one would expect to obtain a simple S-shaped curve (Fig. 8). The curve plotted in Fig. 9 (Colorado through Nebraska) probably lies between the points A and B on the theoretical curve. There are too few soil samples to establish the exact graphical nature of the relationship between organic matter content and rainfall, but apparently it is a curve.

The relationship between humus content and precipitation over this same area is likewise a curve (Fig. 9).

The data from Colorado and Kansas seem to indicate a linear relationship between precipitation and both organic matter content and humus content. However, these samples were few in number and represent a smaller area than the one studied in Colorado and Nebraska. It is more likely that these two lines coincide with a relatively straight-line portion of a curve.

It is quite evident from Fig. 10 that a linear relationship exists between relative humus color and precipitation. On the other hand, the curves for the relative pigment contents are very similar to the

organic matter and humus curves across Nebraska (Fig. 9). Even across Kansas this relationship is seen to be a curve.

The humus contents of all soils in Nebraska and closely adjacent areas, when calculated by the colorimetric method, were found to agree rather closely with those obtained by the gravimetric method. However, for more southern or western soils the humus content as calculated colorimetrically was much too low, and conversely the

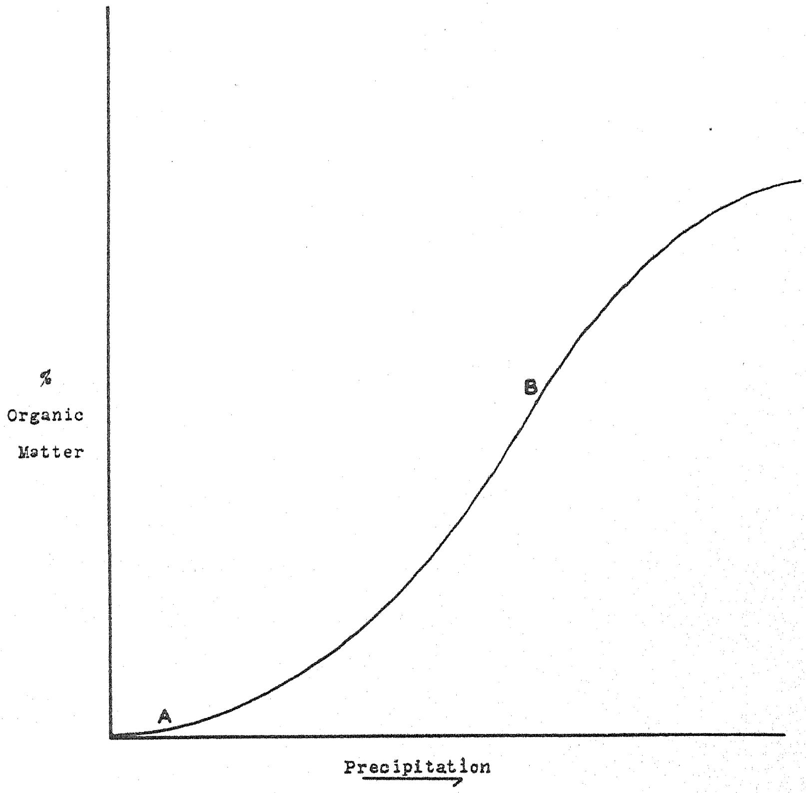

FIG. 8.—Theoretical curve showing the relationship between mean annual precipitation and soil organic matter content.

humus content for more northern soils was too high. This discrepancy is due to the differences in relative pigment contents in the soils from the widely separated areas.

Soils from the podsol, laterite, red and yellow, gray-brown forest, prairie, chernozem, chestnut and brown grassland groups have been leached and every one yielded a jet black to very dark brown solution. The extracts from the laterite, podsol, gray-brown forest, and red and yellow groups were a bit too orange to match the standard perfectly. This difference in color is probably significant and may indicate a difference in the constitution of the pigment, or it may merely

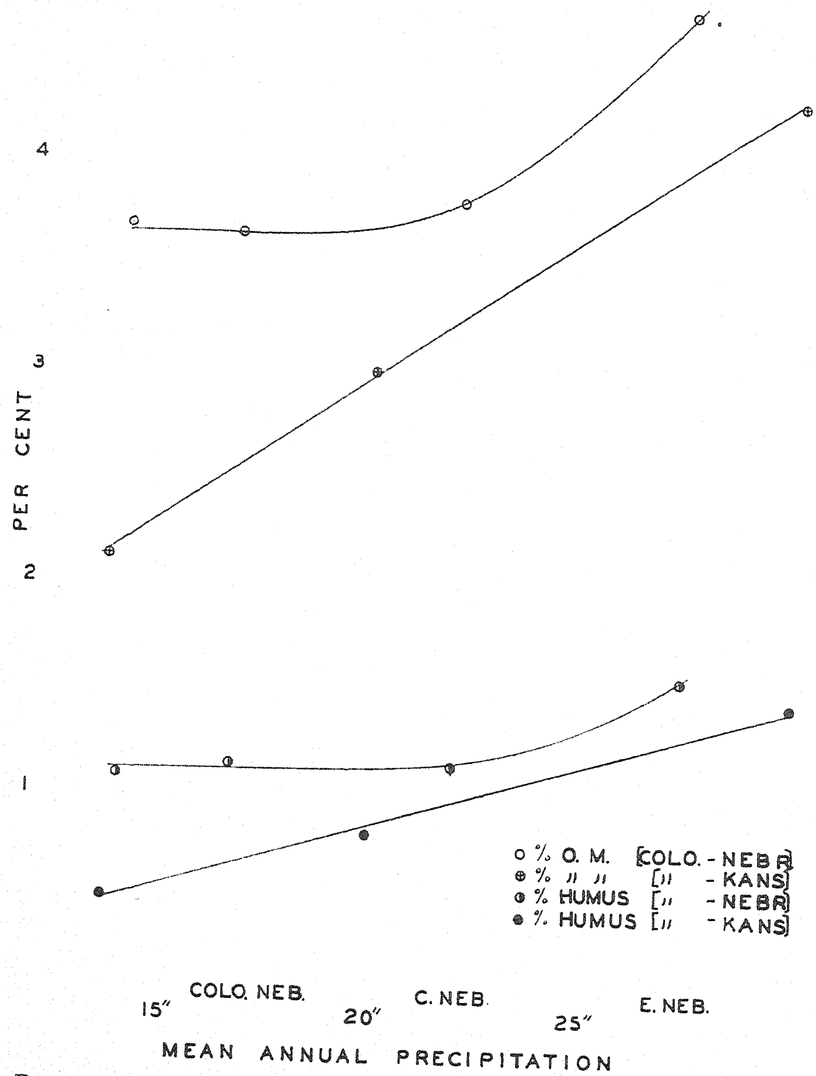

FIG. 9.—Relationship between mean annual precipitation and the relative humus content and organic matter content where the mean annual temperature is 48 to 50° F.

indicate the presence of different indicators or materials in suspension or solution.

With many of the samples studied it was found that, although they might be relatively high in organic matter content, it did not necessarily follow that they were the darkest colored soils or that they contained the most pigment. On the contrary, many soils relatively

low in organic matter content had the highest relative amount of pigment.

COMPARISON OF SOIL GROUPS

From the data assembled in Table 1 a very general comparison of the relative pigment contents, percentage humus, and relative humus color of the soil groups can be made.

TABLE 1.—*Comparison of several soil groups with respect to their relative humus and pigment contents.**

Soil group and series	Humus, %	Organic matter, %	Relative humus color	Relative pigment content	Hygroscopic coeff.	% humus, HC = 10	Relative pigment content, HC = 10
Laterite:							
Nipe	2.31	—	38	46	19.0	1.21	24
Red and Yellow:							
Davidson	1.23	4.20	20	13	14.0	0.88	9
Cecil	0.60	1.69	20	6	5.8	1.03	10
Norfolk	0.56	1.86	37	11	2.3	2.43	48
Durham	1.08	4.10	27	16	4.2	2.57	38
Podsol:							
Onaway	8.12	—	48	208	—	—	—
Gray-brown forest soils:							
Ontonagon	2.08	5.1	64	71	5.3	3.92	133
———	0.74	2.68	48	19	4.2	1.76	45
Bellefontaine	0.84	2.86	76	34	3.8	2.21	89
Fox	0.76	2.32	60	24	4.5	1.68	53
Newton	0.83	2.32	51	22	2.9	2.86	76
———	1.45	—	62	48	—	—	—
Chernozem							
Barnes	1.77	5.88	137	128	15.0	1.18	86
Barnes	1.79	5.93	121	115	14.4	1.24	80
Barnes	2.55	6.97	138	187	15.5	1.64	121
Barnes	1.88	5.85	109	109	13.5	1.39	80

*Samples taken from top 6 to 8 inches.

Concerning the relative humus content we note that the podsol possesses the greatest amount. Making our comparisons on an equivalent textural basis, we note further that the gray-brown forest soils are second, followed by the red and yellow group, the chernozem group, and finally the laterite. Curiously, the Nipe sample was found to contain practically as much humus as the Barnes soils.

The relative pigment content of these soil groups was found to be highest for the podsol, followed by the chernozem, gray-brown forest, red and yellow, and laterite groups. The high value for the podsol was no doubt due to the presence of a large amount of partially decomposed organic debris from the forest floor. Thus, if we consider the mineral portion of the surface soil, the chernozem group possesses the highest pigment content, followed by gray-brown forest group, and finally the red and yellow and laterite groups. The soil groups fall in the same order when we consider the relative humus color of the extracts. The extracts from the chernozem soils were by far the blackest, as shown by column three. Next in order came the gray-brown

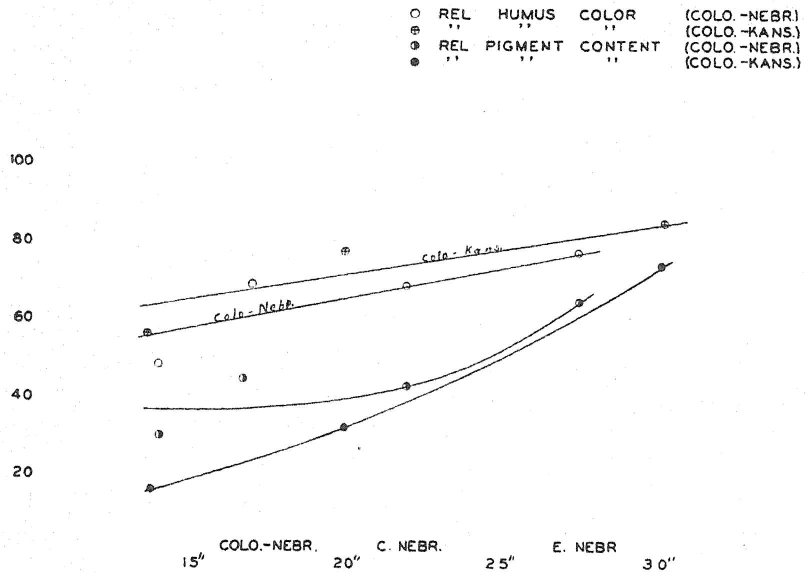

FIG. 10.—Relationship between mean annual precipitation and the relative pigment content and relative humus color where the mean annual temperature is 48° to 50° F.

forest soils, and the podsol. The Nipe extract was as dark as any of the extracts from soils of the red and yellow groups.

CONCLUSIONS

1. Soils having a relatively high organic matter content do not necessarily have the highest pigment content, nor are they always the darkest in color.

2. The second 6 inches of all samples studied were lower than the top 6 inches in relative pigment content.

3. The relative humus color of the soil extract is proportional to the relative pigment content.

4. In regions of approximately equal rainfall, a sigmoid is obtained when organic matter content or relative humus content is plotted against mean annual temperature.

5. Equal differences in precipitation influence the relative pigment, organic matter, and humus contents of the soil more in eastern Nebraska than in western Nebraska.

6. Generally speaking, it can be said that for every fall of 18° F (10° C) in mean annual temperature along the two isohyetal lines studied the average soil organic matter and humus contents are approximately doubled, the relative pigment content of the soil is increased two to six times, and the relative humus color is increased two to three times.

7. Equal differences in mean annual temperature have a greater effect on the relative pigment, organic matter, and humus contents of the soil in the area of greater precipitation.

8. With increasing precipitation along an isothermal line the average soil organic matter, relative humus content, and relative pigment content increase, the graphical nature of these relationships being a curve; but the relative humus color increases linearly.

9. With increasing temperature, along the isohyets, a linear decrease of relative pigment content and relative humus color was noted.

10. The relative pigment content and relative humus color of soil or of sand cultures were not appreciably increased by the addition of organic materials and subsequent decomposition over a period of 62 weeks.

11. Of all soil groups studied the relative humus content was highest in the podsol sample, followed in order by the gray-brown forest soils, the red and yellow soils, the chernozem samples, and finally the laterite.

12. The relative pigment content and humus color, excluding the surface few inches of the podsol, were greatest for the chernozem soils followed by the gray-brown forest soils, the laterite, and red and yellow soils.

13. The laterite and red and yellow samples were fairly high in humus content but low in relative pigment content.

LITERATURE CITED

1. ALWAY, F. J., and PINCKNEY, R. M. The photometric and colorimetric determination of humus. Nebr. Agr. Exp. Sta., 25th Ann. Rpt., 2–16. 1911.
2. CARR, R. H. Is the humus content of a soil a guide to fertility? Soil Science, 3:515–524. 1917.
3. EDEN, T. A note on colorimetric estimation of humic matter in mineral soils. Jour. Agr. Sci., 14:469–472. 1924.
4. GILLAM, W. SHERMAN. The chemical nature and distribution of soil black pigment. Doctor's thesis, Univ. of Nebr. 1938.
5. GORTNER, R. A. The organic matter of the soil: I Some data on humus, humus carbon and humus nitrogen. Soil Science, 2:395–440. 1916.
6. JENNY, HANS. A study on the influence of climate upon the nitrogen and organic matter content of the soil. Agr. Exp. Sta. Bul. 152:15, 18. 1930.
7. JUDD, B. I., and WELDON, M. D. Some changes in the soil during natural succession of vegetation after abandonment in western Nebraska. Jour. Amer. Soc. Agron., 31: No. 3 (1939).
8. RUSSEL, J. C., and ENGLE, E. B. Soil horizons in the central prairies. Amer. Soil Survey Assoc. Bul. 6:1–18. 1925.
9. ————. A method for the continuous automatic extraction of soils. Soil Science, 36:447–450. 1933.
10. ———— and MCRUER, W. G. The relation of organic matter and nitrogen content to series and type in virgin grassland soils. Soil Science 24:448. 1927.
11. STRZEMIENSKA, MARJA. Relation between coloration of alkaline extract of soil and its content of lignin humic complex. Polish Agr. Forest Ann., 32:25–33. 1934.

THE NITROGEN CONTENT OF GRASSES AS INFLUENCED BY KIND, FREQUENCY OF APPLICATION, AND AMOUNT OF NITROGENOUS FERTILIZER[1]

R. I. MUNSELL AND B. A. BROWN[2]

MUCH interest has developed in the problem of maintaining a uniformly high protein content in pasture herbage throughout the grazing season. There are two possible methods of attaining this goal, *viz.*, keeping a high percentage of clover in the sward, and fertilizing the grasses with carriers of nitrogen. It is well known that it is difficult to maintain year after year a large amount of clover in the pastures of the northeastern United States. The experience of the Storrs Agricultural Experiment Station indicates that this is due primarily to the competition of grasses such as Kentucky bluegrass and Rhode Island bent.

A closely related problem is that of maintaining a continuously thrifty lawn free from clover and weeds. Application of certain nitrogenous fertilizers offers the possibility not only of preserving pure stands of lawn grasses but also of helping to maintain a more uniform growth throughout the season.

This paper deals with one phase of a rather broad project which was undertaken to study the effects of various chemicals on the soil, on the botanical composition of the sward, and on the stands of Kentucky bluegrass and Rhode Island bent grasses. The particular phase to be considered here is the effect of the chemical treatments on total nitrogen content of the herbage.

EXPERIMENTAL METHODS

The site of this experiment is a nearly level field of Charlton fine sandy loam soil, a type above the average of Connecticut soils in moisture retentiveness. Since the spring of 1936, 17 different nitrogenous treatments have been applied to triplicate plats, 25 by 6 feet, of pure stands of Kentucky bluegrass and Rhode Island bent which had been seeded in late August of the previous year. Previous to seeding, the pH of the soil was 5.28, and the available phosphorus by the Truog method was 66 pounds per acre. At the time of seeding, 16% superphosphate was applied at the rate of 500 pounds per acre. Carriers of nitrogen only have been added since seeding.

Whenever the tallest herbage of either grass reached a height of 3½ inches, the 64 plats in that particular block were cut with a motor lawnmower equipped with a grass catcher. The clippings were dried and later ground in a Wiley mill for analysis. The nitrogen content of the samples was determined according to the Gunning method for total nitrogen without nitrates (4).[3]

Analyses had previously been run on samples of Kentucky bluegrass under similar fertilization from an adjacent field to determine how much of the total

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station, Storrs, Conn. Also presented at the annual meeting of the American Society of Agronomy, Washington, D. C., November 16–18, 1938. Received for publication December 29, 1938.

[2]Research Assistant and Associate Agronomist, respectively.

[3]Reference by number in parenthesis is to "Literature Cited", p. 398.

nitrogen in the grass was in the inorganic forms of nitrate and ammonia. On a dry matter basis, 19 samples analyzed for ammonia varied from 0.001 to 0.016%, or an average of 0.005%. Thirty-nine samples analyzed in 1933 for nitrates varied from 0 to 0.270%, or an average of 0.070%. In 1934, 22 samples contained a minimum of 0 nitrates and a maximum of 0.270%, or an average of 0.040%. In view of the low average nitrate content of Kentucky bluegrass, the procedure for the reduction of nitrates was omitted in the determination of total nitrogen in the present experiment. The data presented in this paper are based on the analyses of samples harvested in 1936 and 1937.

RESULTS AND DISCUSSION

NITROGEN CARRIER

The first factor to be considered is the carrier of nitrogen. All the nitrogen carriers were applied immediately after cutting, except in April, in three applications of 28 pounds actual nitrogen each in April and again in June and August. The analyses of both grasses under eight different fertilizer treatments for each cutting in 1936 and 1937 are given in Tables 1 and 2 and are shown graphically in Fig. 1.

TABLE 1.—*Effects of source of nitrogen on percentage of nitrogen in dry matter of Kentucky bluegrass.*

Source of nitrogen	1936							
	May 14	June 10	July 1	July 30	Aug. 25	Sept. 22	Nov. 5	Average
None added	2.82	2.36	2.50	2.45	2.45	2.84	2.49	2.56
Sodium nitrate	3.52	2.24	2.30	3.00	2.51	2.55	2.73	2.69
Ammonium sulfate	3.68	2.17	2.21	2.94	2.58	3.47	2.65	2.81
Ammonium carbonate	3.08	2.28	2.32	2.41	2.33	2.94	2.44	2.54
Ammonium chloride	3.68	2.34	2.24	2.80	2.48	3.41	2.59	2.79
Calcium nitrate	3.84	2.29	2.30	2.91	2.58	3.48	2.34	2.82
Cyanamid	3.63	2.17	2.29	2.80	2.62	3.37	2.46	2.76
Urea	3.43	2.17	2.31	2.75	2.56	3.42	2.78	2.77
Calnitro	3.74	2.35	2.50	2.94	2.60	3.12	2.67	2.85
	1937							
	May 18	June 8	June 29	July 19	Aug. 19	Sept. 3	Oct. 5	Average
None added	2.34	2.35	2.62	2.76	1.96	2.45	2.81	2.47
Sodium nitrate	2.72	2.30	2.62	3.55	2.21	3.98	3.01	2.91
Ammonium sulfate	2.57	2.20	2.48	3.64	2.38	4.39	2.97	2.95
Ammonium carbonate	2.57	2.30	2.71	3.37	2.19	3.31	2.96	2.77
Ammonium chloride	2.52	2.15	2.60	3.34	2.38	3.92	2.81	2.82
Calcium nitrate	2.78	2.34	2.72	3.33	2.40	4.26	3.00	2.98
Cyanamid	2.54	2.36	2.47	3.59	2.58	3.99	2.77	2.90
Urea	2.59	2.19	2.43	3.41	2.38	4.12	2.94	2.87
Calnitro	2.80	2.32	2.37	3.65	2.44	4.22	2.92	2.96

TABLE 2.—*Effects of source of nitrogen on percentage of nitrogen in dry matter of Rhode Island bent grass.*

Source of nitrogen	1936					
	May 18–19	June 16	July 22	Sept. 14–16	Nov. 3–5	Average
None added	2.85	2.20	2.19	2.32	2.24	2.36
Sodium nitrate	3.36	2.19	2.75	3.06	2.40	2.75
Ammonium sulfate	3.51	2.09	2.66	3.16	2.37	2.76
Ammonium carbonate	2.99	2.15	2.25	2.46	2.17	2.40
Ammonium chloride	3.36	2.18	2.63	3.12	2.35	2.73
Calcium nitrate	3.45	2.18	2.72	3.09	2.38	2.76
Cyanamid	3.29	2.24	2.67	3.10	2.55	2.77
Urea	3.41	2.27	2.51	3.06	2.39	2.73
Calnitro	3.49	2.19	2.63	3.13	2.47	2.78

Source of nitrogen	1937						
	June 1	June 23	July 20	Aug. 28	Sept. 18	Oct. 26	Average
None added	2.45	2.69	3.25	2.92	3.40	2.66	2.90
Sodium nitrate	2.37	2.73	3.29	2.70	3.90	2.62	2.94
Ammonium sulfate	2.33	2.61	3.14	2.60	3.69	2.31	2.78
Ammonium carbonate	2.30	2.49	2.99	2.64	3.52	2.39	2.72
Ammonium chloride	2.39*	2.61	3.04	2.43	3.65	2.23	2.73
Calcium nitrate	2.20	2.65	3.26	2.61	3.74	2.54	2.83
Cyanamid	2.41	2.82	3.22	2.79	3.61	2.66	2.92
Urea	2.46	2.80	3.12	2.77	3.77	2.54	2.91
Calnitro	2.55*	2.83	2.98	2.97	3.70	2.61	2.94

*Estimated.

In general, the application of nitrogen produced a significant increase in the nitrogen content of the herbage. However, a study of the yearly averages for both grasses reveals two exceptions as follows: (a) Due to the inexplicably high nitrogen content of the herbage from the Rhode Island bent check plats in 1937, none of the eight nitrogen carriers produced a significant increase in total nitrogen; and (b) in all cases ammonium carbonate, in contrast to the other seven sources of nitrogen, failed to produce a significant increase over the untreated plats.

It is evident from a study of Fig. 1 that the nitrogen content of both grasses was higher in 1937 than in 1936. The weather data given in Table 3 indicate that this was probably due to more favorable rainfall in 1937. May was the only month in 1937 in which the precipitation was definitely lower than the corresponding month in 1936. The wet August of 1937 made the August applications of nitrogen particularly effective. In general, both years were wetter than the 49-year average. A month by month comparison with the long time average shows that July 1936 and May and July 1937 were the only months during the two growing seasons which were below normal in this respect.

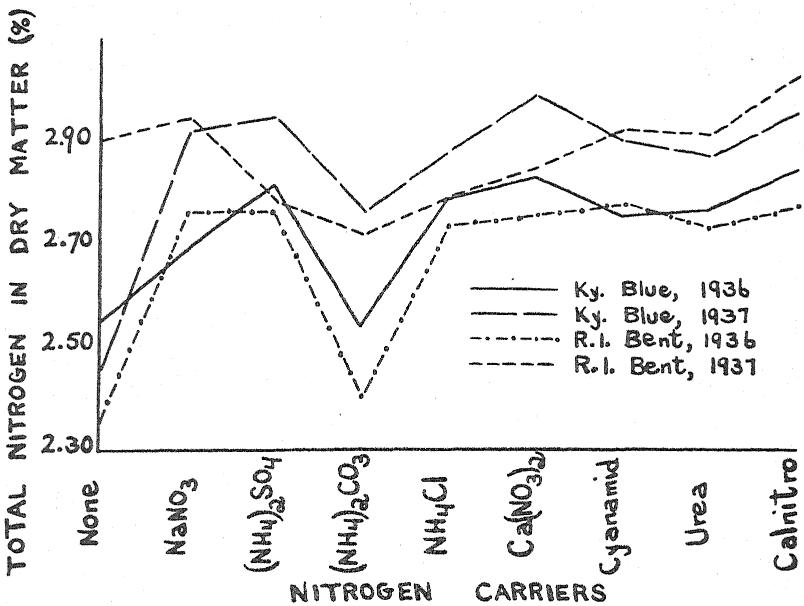

FIG. 1.—Effects of source of nitrogen on percentage of nitrogen in the dry matter of Kentucky bluegrass and Rhode Island bent grasses, 1936 and 1937.

TABLE 3.—*Weather at Storrs, Conn., during growing seasons.*

Year	April	May	June	July	Aug.	Sept.	Oct.	Average or total
			Mean Temperature, ° F					
1936	43.10°	59.18°	65.64°	69.28°	69.84°	62.88°	51.71°	60°
1937	44.67°	58.60°	66.85°	71.18°	72.42°	60.07°	49.70°	61°
Average, 1888–1937	45.23°	56.42°	64.88°	69.10°	67.59°	60.89°	50.74°	59°
			Total Precipitation, Inches					
1936	3.59	4.33	4.60	2.60	6.23	4.50	5.06	30.91
1937	4.83	3.23	4.67	2.55	9.10	4.46	5.45	34.29
Average, 1888–1937	3.51	3.46	3.11	4.18	4.14	3.84	3.59	25.83

FREQUENCY OF APPLICATION

Another phase of this investigation dealt with the frequency of application of the same amount of nitrogenous fertilizers and the effect on nitrogen content. Results of the different treatments are given in Tables 4 and 5 and in the case of Kentucky bluegrass are shown graphically in Figs. 2 and 3.

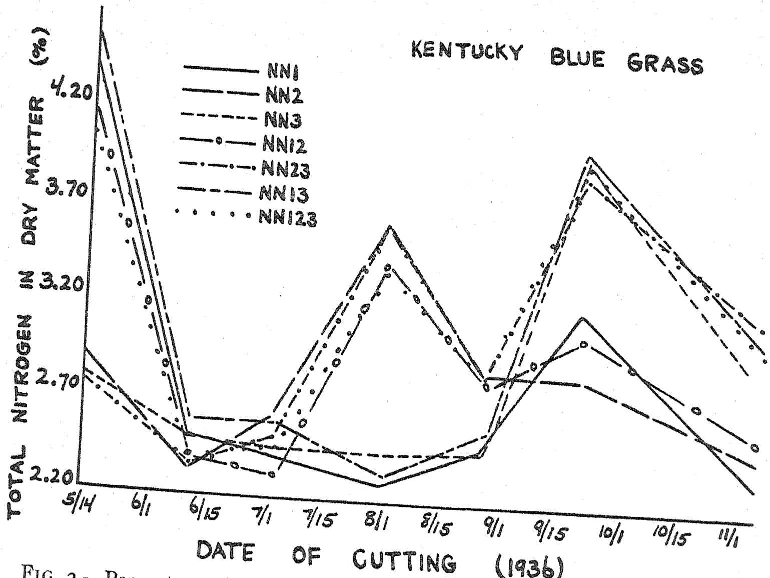

FIG. 2.—Percentage of nitrogen in the dry matter of Kentucky bluegrass as affected by the frequency of application of calnitro, 1936.

TABLE 4.—*Percentage of nitrogen in the dry matter of Kentucky bluegrass as affected by the frequency of application of calnitro.*

Treatments*	1936							
	May 14	June 10	July 1	July 30	Aug. 25	Sept. 22	Nov. 5	Average
NN1	4.38	2.49	2.43	2.27	2.47	3.20	2.38	2.80
NN12	4.15	2.44	2.34	3.44	2.86	3.09	2.62	2.99
NN123	4.09	2.43	2.45	3.43	2.87	3.98	3.08	3.19
NN2	2.87	2.28	2.66	3.67	2.93	2.91	2.52	2.83
NN23	2.76	2.39	2.54	3.67	2.90	3.94	3.21	3.06
NN13	4.54	2.62	2.59	2.30	2.49	4.11	3.10	3.11
NN3	2.79	2.48	2.47	2.45	2.46	4.00	2.97	2.80
None	2.82	2.36	2.50	2.45	2.45	2.84	2.49	2.56
	1937							
	May 18	June 8	June 29	July 19	Aug. 19	Sept. 3	Oct. 5	Average
NN1	3.24	2.60	2.68	3.04	2.46	2.73	2.51	2.75
NN12	3.14	2.51	2.82	4.25	2.83	3.40	2.82	3.11
NN123	3.07	2.60	2.90	4.30	2.97	4.77	3.30	3.41
NN2	2.53	2.34	2.71	4.11	2.35	3.00	2.80	2.83
NN23	2.43	2.36	2.74	3.93	2.60	4.60	3.28	3.13
NN13	3.01	2.62	2.70	3.12	2.42	4.58	3.31	3.11
NN3	2.54	2.58	2.96	2.93	1.98	4.24	3.23	2.92
None	2.34	2.35	2.62	2.76	1.96	2.45	2.81	2.47

*All nitrogen from calnitro. NN = 56 pounds elemental nitrogen. 1 = applied in April; 2 = applied in June; and 3 = applied in August.

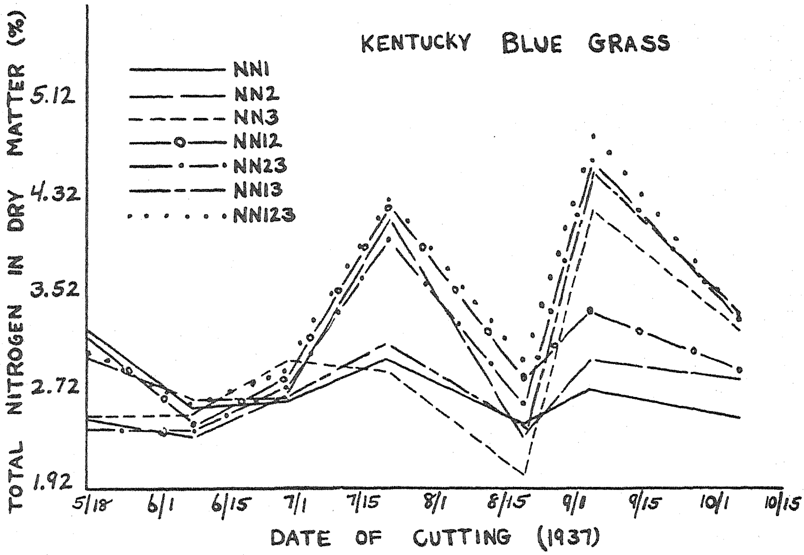

FIG. 3.—Percentage of nitrogen in the dry matter of Kentucky bluegrass as affected by the frequency of application of calnitro, 1937.

TABLE 5.—*Percentage of nitrogen in the dry matter of Rhode Island bent grass as affected by the frequency of application of calnitro.*

Treatments*	1936					
	May 18–19	June 16	July 22	Sept. 14–16	Nov. 3–5	Average
NN1	3.64	2.46	2.35	2.37	2.30	2.62
NN12	3.85	2.31	2.97	2.30	2.22	2.73
NN123	3.83	2.43	2.98	3.52	2.63	3.08
NN2	2.92	2.17	2.82	2.26	2.16	2.47
NN23	2.82	2.19	2.77	3.49	2.60	2.77
NN13	3.97	2.34	2.13	3.75	2.71	2.98
NN3	3.09	2.16	2.04	3.84	2.58	2.74
None	2.85	2.20	2.19	2.32	2.24	2.36

	1937						
	June 1	June 23	July 20	Aug. 28	Sept. 18	Oct. 26	Average
NN1	2.79	3.04	2.93	2.96	3.12	2.54	2.89
NN12	2.72	3.09	3.46	3.10	3.19	2.48	3.01
NN123	2.65	3.03	3.55	3.18	4.39	3.36	3.36
NN2	2.37	2.62	3.56	3.07	3.29	2.44	2.89
NN23	2.38	2.57	3.64	3.13	4.53	2.98	3.21
NN13	2.80	2.95	2.98	2.91	4.41	2.96	3.17
NN3	2.42	2.81	3.10	3.04	4.35	3.00	3.12
None	2.45	2.69	3.25	2.92	3.40	2.66	2.90

*See footnote to Table 4.

Calnitro was the only source of nitrogen on this section and was added at a rate to furnsih nitrogen at 56 pounds per application.

In both years, Kentucky bluegrass from plats receiving nitrogen in April only had its highest nitrogen content in the first cutting in May. There was a rapid drop in June and no further marked increase during the season.

A study of Figs. 2 and 3 reveals that the response to April nitrogen of Kentucky bluegrass was much more marked in 1936 than in 1937. Three factors may have contributed to the lower response in 1937, *viz.*, (a) the calnitro was applied seven days earlier in 1937; (b) the first cutting was made four days later; and (c) the first two weeks of May were cold and dry as compared with the same period in 1936.

The Rhode Island bent plats showed the same general tendency except for the variation caused by not mowing until June 1 in 1937. In that case, the greater maturity of the grass and the longer period of time elapsed since fertilization largely masked the effect of the April nitrogen on the nitrogen content.

Grass from plats receiving all their nitrogen in June had the highest total nitrogen in July, while the August nitrogen application had its maximum effect in September. The relatively high response to August nitrogen in 1937 was probably due to the abnormally high rainfall in late August and early September.

These results suggest the possibility of controlling the seasonal peaks in total nitrogen of the herbage by adding or withholding available nitrogenous fertilizers. In regard to yields, a similar suggestion was made by Brown and Munsell (1), who reported the results of a study of the effects of time and frequency of application of nitrogen on the yields of Kentucky bluegrass and Rhode Island bent grasses. They showed the possibility of delaying the peak of high production to mid-summer or even late summer by withholding the April or both the April and June application of nitrogen until June or August. However, it should be noted that relatively high amounts of nitrogen (56 pounds) were necessary to accomplish that change.

In the present experiment, regardless of number of applications of nitrogen per season, most of the effects of the nitrogen were reflected in the succeeding cutting. The second cutting after the application showed little or no effect. Mortimer and Ahlgren (3) concluded from their study of Kentucky bluegrass fertilization that high nitrogen content is produced only where frequent applications of nitrogen are made throughout the growing season. Similar conclusions were reached by Enlow and Coleman (2) from their study of Bahia, carpet, and centipede grasses in Florida.

At Storrs when three applications of nitrogen at 56 pounds each were made in April, June, and August, three successive peaks in total nitrogen content were produced. Each sharp rise occurred at the next cutting following applications, and even with this large amount of nitrogen, the effect of the fertilization disappeared within a month.

AMOUNT OF FERTILIZER

A third phase of the investigation was concerned with the variations in total nitrogen content of the two grasses when different amounts

of fertilizer were applied. The results of six applications of nitrogen per season at 14 pounds are also included in this section. Results are given in Table 6 and are shown graphically for Rhode Island bent grass in Fig. 4.

TABLE 6.—*Percentage of nitrogen in the dry matter of Kentucky bluegrass and Rhode Island bent grass as affected by amounts of calnitro.*

Treatments*	Kentucky bluegrass, 1936						
	May 14	June 10	July 1	July 30	Aug. 25	Sept. 22	Nov. 5
None	2.82	2.36	2.50	2.45	2.45	2.84	2.49
N/2 (15th Apr.–Sept.)	3.16	2.61	2.47	2.56	2.48	2.90	3.28
N123	3.74	2.35	2.50	2.94	2.60	3.12	2.67
NN123	4.09	2.43	2.45	3.43	2.87	3.98	3.08

Treatments*	1937						
	May 18	June 8	June 29	July 19	Aug. 19	Sept. 3	Oct. 5
None	2.34	2.35	2.62	2.76	1.96	2.45	2.81
N/2 (15th Apr.–Sept.)	2.58	2.68	2.94	3.39	2.81	3.78	3.16
N123	2.80	2.32	2.37	3.65	2.44	4.22	2.92
NN123	3.07	2.60	2.90	4.30	2.97	4.77	3.30

Treatments*	Rhode Island bent grass, 1936				
	May 18–19	June 16	July 22	Sept. 14–16	Nov. 3–5
None	2.85	2.20	2.19	2.32	2.24
N/2 (15th Apr.–Sept.)	3.07	2.33	2.36	2.95	3.05
N123	3.49	2.19	2.63	3.13	2.47
NN123	3.83	2.43	2.98	3.52	2.63

Treatments*	1937					
	June 1	June 23	July 20	Aug. 28	Sept. 18	Oct. 26
None	2.45	2.69	3.25	2.92	3.40	2.66
N/2 (15th Apr.–Sept.)	2.35	3.07	3.00	2.96	3.55	2.74
N123	2.55	2.83	2.98	2.97	3.70	2.61
NN123	2.65	3.03	3.55	3.18	4.39	3.36

*N/2 = 14 pounds elemental nitrogen per application; N = 28 pounds elemental nitrogen per application; NN = 56 pounds elemental nitrogen per application. 1 = applied in April; 2 = applied in June; and 3 = applied in August.

The summary in Table 7 shows the average amount of variation in total nitrogen with change in rate of application of calnitro.

It is evident that calnitro applied in equal total amounts was equally efficient whether applied in three applications or in six monthly applications. However, the graphs show that the six monthly treatments maintained a somewhat more uniform nitrogen content throughout the growing season. While there were some fluctuations,

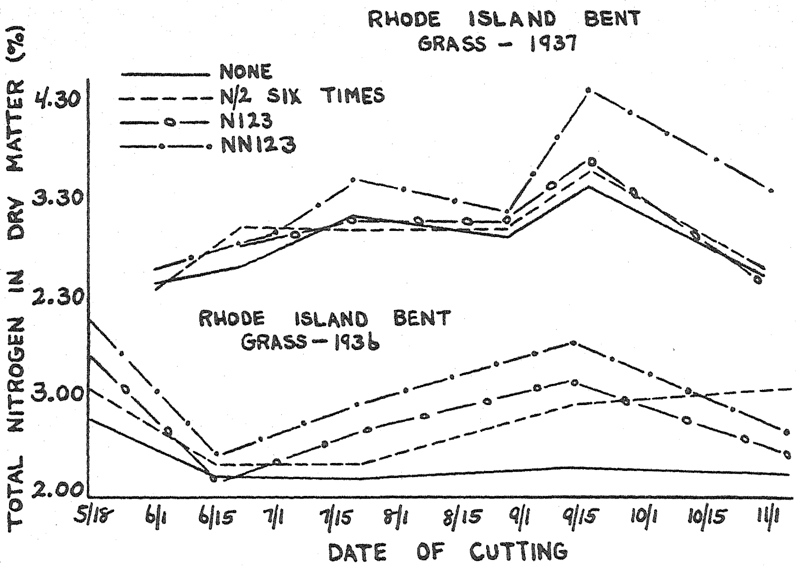

FIG. 4.—Percentage of nitrogen in the dry matter of Rhode Island bent grass as affected by the amount of calnitro applied, 1936 and 1937.

TABLE 7.—*Variation in total nitrogen with change in rate of application of calnitro.*

Pounds of N		Kentucky bluegrass		Rhode Island bent grass	
Per application	Per season	Total N (%), av. 2 years	Increase over no treatment	Total N (%), av. 2 years	Increase over no treatment
0	0	2.52	—	2.63	—
14	84	2.92	0.40	2.85	0.22
28	84	2.91	0.39	2.90	0.27
56	168	3.30	0.78	3.22	0.59

they were less extreme than where the calnitro was applied only three times per season.

When applications of calnitro were increased to add 56 pounds of actual nitrogen three times annually, the total nitrogen increased 0.39% in Kentucky bluegrass and 0.32% in Rhode Island bent over the 28-pound treatments.

RECOVERY OF NITROGEN

To secure some measure of the efficiency of the various nitrogen carriers and also of the different times and frequencies of application of calnitro, calculations were made of the recovery of nitrogen. In making these calculations, the amount of nitrogen recovered in the crop from the untreated plat was subtracted from the amount obtained in the treated plats.

In the first half of Table 8 are given the 2-year average percentages of nitrogen recovered for both grasses for the eight nitrogen carriers. The relative rankings are shown also. It is clear that the best recoveries were obtained from calnitro, calcium nitrate, nitrate of soda, and sulfate of ammonia. This was true of both grasses. In the second half of the same table are given the percentages of nitrogen recovered from applications of calnitro at different times during the season.

TABLE 8.—*Recovery of nitrogen (per cent).*

Treatments*	Kentucky bluegrass		Rhode Island bent grass	
	Two-year average	Rank	Two-year average	Rank
Sodium nitrate, N123	41	2	53	4
Ammonium sulfate, N123	40	4	53	3
Ammonium carbonate, N123	8	8	6	8
Ammonium chloride, N123	30	5	20	7
Calcium nitrate, N123	48	1	60	2
Cyanamid, N123	25	7	41	6
Urea, N123	25	6	46	5
Calnitro, N123	41	3	63	1
Calnitro, NN1	51	4	70	1
Calnitro, NN12	57	1	65	2
Calnitro, NN123	52	3	61	4
Calnitro, NN2	51	5	59	5
Calnitro, NN23	48	7	57	6
Calnitro, NN13	53	2	63	3
Calnitro, NN3	34	8	45	7
Calnitro, N/2 (15th Apr.–Sept.)	50	6	44	8

*N/2 = 14 pounds elemental nitrogen per application; N = 28 pounds elemental nitrogen per application; NN = 56 pounds elemental nitrogen per application. 1 = applied in April; 2 = applied in June; and 3 = applied in August.

In this comparison the largest recoveries were obtained with both grasses when the treatments included an application of nitrogen in April. August nitrogen was the least efficient, with June applications intermediate. This fact also corroborates the data on yields obtained in another experiment.

SUMMARY

A study of the effects of various sources of nitrogen and frequencies and rates of application of calnitro on the nitrogen content of Kentucky bluegrass and Rhode Island bent grass was made for 1936 and 1937. The results are summarized as follows:

1. Of eight nitrogen carriers applied to pure stands of Kentucky bluegrass and Rhode Island bent grass, ammonium carbonate alone failed to give significant increases in total nitrogen over the untreated plats. In this respect there were no appreciable differences between the other seven sources of nitrogen.

2. The data on frequency of application of calnitro show that marked increases in total nitrogen in both grasses occurred only in the first cutting after the fertilizer was applied. After about a month, the influence of the calnitro was no longer manifest.

3. A single application of nitrogen in April produced its greatest effect in May, after which the nitrogen content fell rapidly and remained low for the rest of the season. By withholding the fertilizer until June or August, the highest point in total nitrogen for the season was reached in the succeeding cutting. However, a relatively high rate of nitrogen application (56 pounds) was required to attain this end.

4. In regard to amount and frequency of applying nitrogen, 14 pounds applied, six times during the season produced practically the same increase in average nitrogen content over no treatment as three applications of 28 pounds. However, there was less fluctuation when applications were made six times per season. When 56 pounds of nitrogen were applied three times (168 pounds per season), further increases of 0.39% in the case of Kentucky bluegrass and 0.32% in the case of Rhode Island bent were obtained in the average contents of nitrogen.

5. The percentage recoveries of nitrogen indicated that calnitro, calcium nitrate, ammonium sulfate, and sodium nitrate were more efficient than the other four carriers. When calnitro was applied at different times during the season, the greatest recovery was obtained from the plats receiving nitrogen only in April. August nitrogen was the least efficient, with June intermediate.

LITERATURE CITED

1. Brown, B. A., and Munsell, R. I. Pasture investigations (eighth report): Modifying the seasonal growth habits of grasses. Storrs (Conn.) Agr. Exp. Sta. Bul. 209. 1936.
2. Enlow, C. R., and Coleman, J. M. Increasing the protein content of pasture grasses by frequent light applications of nitrogen. Jour. Amer. Soc. Agron., 21:845–853. 1929.
3. Mortimer, G. B., and Ahlgren, H. L. Influence of fertilization, irrigation and stage and height of cutting on yield and composition of Kentucky bluegrass (*Poa pratensis* L.). Jour. Amer. Soc. Agron., 28:515–533. 1936.
4. Official and Tentative Methods of Analysis of the A. O. A. C. Ed. 3, 1930. (Chapter II, paragraphs 22 and 19.)

PASTURE YIELDS AND CONSUMPTION UNDER GRAZING CONDITIONS[1]

R. F. Fuelleman and W. L. Burlison[2]

INVESTIGATIONS of pasture yields and consumption under actual grazing conditions have been carried on for a number of years at the Illinois Experiment Station. Although a vast amount of experimental research in pastures and pasture plants has been and is being performed at the various experiment stations in this and foreign countries, it is usually conceded that specific results are broadly localized depending upon a number of ecological factors. This means that within the confines of a rather restricted area the farmers feel that they must depend upon the experimental results of their own local and state experiment stations.

Practical information relative to pastures, pasture plants, and utilization is demanded by farmers in ever-increasing number. The motivating forces behind this demand, economic or otherwise, have brought forward the very pertinent fact that the agricultural industry as a whole is vitally interested in pastures and pasture improvement. The hackneyed phrase that "The most economical source of nutrients is good pasture," is true for most types of livestock, and the proper utilization of pasturage is important to the success of any livestock enterprise. The demand for information previously mentioned has forced the investigation of many problems, some old and some new.

The practical evaluation of pastures presents a problem in itself of large proportions. There are many methods in use, but no single one has found general use in this country. Lack of uniformity in methods can be ascribed to the wide range of variable ecological and topographical conditions necessitating modifications and changes in technic. The most popular method in use for measuring yields is that of clipping to simulate grazing. Like all methods it is, of course, open to criticism for obvious reasons, but at the present time there apparently is no better method except the measurement of pastures by the use of grazing animals or combinations of clipping and grazing.

The method used in evaluating pasture yields and consumption at Illinois is a modification of that recommended by the Pasture Committee of the American Society of Agronomy. The latter method does not presume to measure consumption directly but rather bases its measure of consumption upon gains in live weights and in animal products. The method as used at this station measures yields by clipping of sample areas as well as by the differences between growth and consumption. The total growth, total consumption, and the residual growth are obtained at the same time. This method is open to criticism particularly from the standpoint of the necessity of

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[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication January 12, 1939.

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selecting so-called "judgment samples." Restrictions of time and expense prevent the use of random sampling.

This paper presents some of the agronomic data and observations from a cooperative project with the Animal Husbandry Department. These data are from the experimental farm pastures at Urbana, Illinois.

METHODS

In 1929 and the succeeding years to 1935, inclusive, a number of 5- and 10-acre fields on the South Animal Husbandry Farm at Urbana, Illinois, were seeded to pasture grasses and legumes. These have included brome grass, *Bromus inermis;* reed canary grass, *Phalaris arundinacea;* orchard grass, *Dactylis glomerata;* Kentucky bluegrass, *Poa pratensis*, and alfalfa, *Medicago sativa*. A number of mixtures were seeded, but the data from these fields are not complete at the present writing.

Brome grass was seeded in mixture with redtop and Kentucky bluegrass, but the dominant vegetation is bromegrass at the present time. Reed canary grass was seeded in the spring of 1935 on a 5-acre field. A small stream drains through this field, but it has an elevation equal to the surrounding crop land. A good stand was secured and it is still a practically pure field of reed canary grass. Kentucky bluegrass has been seeded on several fields and four of these were originally used in these experiments. At the present time two of these pastures are being used for yield and consumption data. Alfalfa was seeded on one 10-acre field in 1934, but data are presented for only one year.

As stated previously, methods of sampling pastures under grazing conditions have not been well developed and the method used here varies with the experimental plan and according to the best judgment of the operators, keeping in mind the fact that accurate and practical results are desired. When the number of samples taken are limited by labor and expense restrictions, it is necessary to take as many samples as possible using judgment in making the selection. This, of course, introduces the possibility of error. But the person making the selection of representative areas soon acquires sufficient experience to enable him to take samples without the introduction of excessive error. However, as different portions of the same pasture vary from each other, so may there be variation among the samples representing an area.

Metal cages were used to protect the sample areas from grazing (Fig. 1). The cages were constructed from 3/8-inch iron rods welded together to form a frame 4 x 4 feet square by 18 inches high. The corner rods extended 12 inches beyond the bottom of the cage and provided anchorage. The top and sides were covered with heavy 2 x 6 inch mesh woven wire welded to the frame.

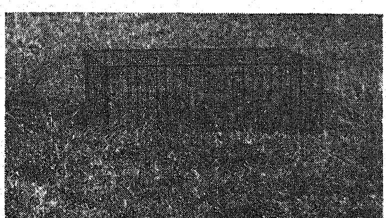

FIG. 1.—Type of metal cage used for protection of sample areas.

A definite procedure was followed in placing the cages. The pastures were divided by imaginary lines into three parts and one set of two cages placed in each part. Three samples were taken from each section of the field on each sampling date. They were designated as "A", "B", and "C", and the different sections of the field designated as 1, 2, and 3, so that samples from the first section would be designated as "1A", "1B", and "1C". The "A" sample consisted of herbage plucked or clipped from beneath a cage which had been placed over a representative grazed area at a previous sampling date or when the cattle were turned in. The sample harvested from a representative grazed area was designated as "C", while sample "B" was composed of the herbage which was harvested from beneath the cage placed on the "C" area on the previous sampling date. "B" is the total growth since the previous sampling date.

The method of harvesting varied to some extent with the growth. Whenever possible, plucking was resorted to but when the material became coarse and tough a grass knife was used.

The harvested herbage was placed in loose cotton bags with proper labels to show their origin. The samples were then weighed and recorded. Then all the "A" samples, "B" samples, and "C" samples respectively from each field were composited and run through a grinder which reduced them to a uniformly small size. From the composited material a sample was taken for air- and oven-dry forage measurements and for chemical analyses. Air drying was accomplished in an oil burner equipped drying house which was heated to 55° to 60° C, reducing the moisture content of the material to approximately 4 or 5%. For oven-dry weights a thermostatically controlled electric oven was used in which the temperature was held at 98° to 100° C. The samples for chemical analysis were placed only in the drying house. From the oven-dry weight the percentage dry matter was calculated.

The use of the "A", "B", and "C" samples gives a measure of the consumption and production of forage. Two methods were used, in making the estimates of yields and consumption, one the "A-C" method and the other the "B-C" method. In this paper the results of the two methods are averaged for in general this average gives a more accurate and uniform picture of the results.

CLIMATIC FACTORS

Yields as well as consumption of forage are very markedly affected by rainfall and temperature. Yield curves have a tendency to parallel rainfall curves, but consumption curves ordinarily do not fluctuate widely during the fore part of the grazing season. There is a tendency on the part of livestock, however, to graze more heavily during the latter part of the season, usually beginning about the first of September. This trend can be ascribed to several things, namely, more moderate temperatures, an increase in rainfall, decrease in troublesome insects, and what may be most important, an apparent increase in palatability.

The growing season of 1935 at Urbana, Illinois, was marked by an abundance of well-distributed rainfall accompanied by moderate

temperatures. Yields and consumption were much greater than during the following season of 1936, which was the reverse of 1935. Rainfall was deficient in June and July of 1936 and temperatures were excessively high. Fig. 2 illustrates graphically total weekly precipita-

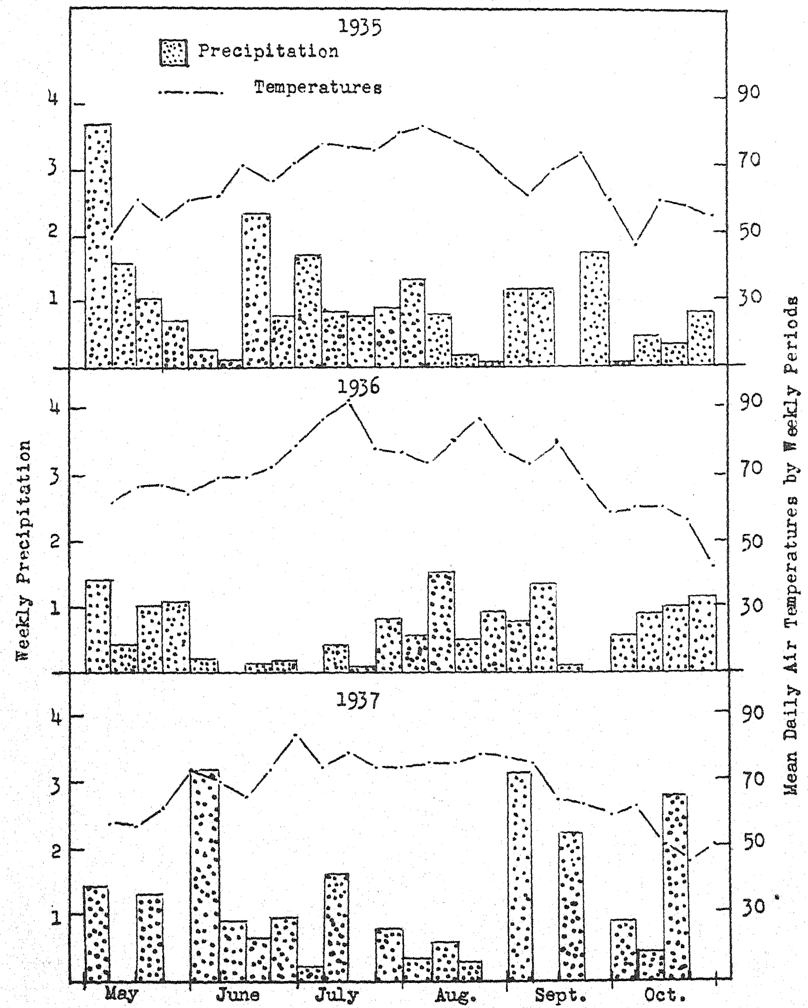

FIG. 2.—Graphs illustrating total weekly precipitation and average daily temperatures by weekly periods for the grazing season of 1935, 1936, and 1937.

tion and average daily temperatures by weekly periods for the growing seasons of 1935, 1936, and 1937. In 1937 the growing season was more nearly normal with respect to precipitation and temperature. Precipitation, with the exception of the latter part of August, was sufficient and the temperatures not excessively high.

DISCUSSION OF RESULTS

This discussion does not include results obtained from all fields used in the experimental setup but chiefly those dealing with pasture species considered of greater importance in this area.

KENTUCKY BLUEGRASS

Kentucky bluegrass, *Poa pratensis*, because of its adaptability, persistence, and aggressiveness is used for pasturage more than any other species, but this grass has several serious deficiencies which restrict its yield, consumption, and apparent palatability. One of these is early maturity. It begins growth very early in the spring and produces seed culms and seed during the latter part of May or early June. Its period of greatest apparent palatability is in late March and during April, usually before it is feasible to turn livestock out to graze. A second peak in consumption occurs in mid-August or early September, depending upon precipitation and temperature. The second deficiency of Kentucky bluegrass and perhaps the most important from the pasture standpoint is summer dormancy. Yields of forage declined during mid-summer periods of 1935, 1936, and 1937. However, the trend of production usually levels off or swings upward in the early fall. Fig. 3 illustrates the yields and consumption of forage on Kentucky bluegrass fields for 1935, 1936, and 1937.

Consumption in 1936 was relatively higher than in 1935. Livestock consumed 85% of the forage available in 1936 as compared with approximately 65% of the forage available in 1935. In 1937 consumption approximately equaled production, but referring to Fig. 3 it will be noted that grazing was continued until November 15. Photosynthetic activity on the part of the plant had practically ceased previous to this date as is evidenced by the yield trends illustrated in Fig. 3 and in Table 1.

Table 1 shows that in 1935, 61% of the total seasonal yields was obtained by June 21 and 83% by July 19. In 1936, 62% of the yield was obtained by May 22 and 84% of the total seasonal yield by June 19, exactly one month in advance of the previous year's 83% mark. The difference is, of course, due to the fact that the total 1936 yield was approximately only 50% of the 1935 yield. The point illustrated by these percentages merely indicates that the first two months of the grazing season usually furnish more than 60% of the season's total forage. Consumption is more nearly equalized throughout the grazing season.

ORCHARD GRASS

Orchard grass, *Dactylis glomerata*, like Kentucky bluegrass, starts growth early in the spring and matures at approximately the same time as the latter. In its ability to yield it compares very favorably with bluegrass. It has several favorable characteristics which make it desirable in pastures. In addition to its early growth, it is apparently quite palatable to cattle and sheep during the fore part of the grazing season and also in the latter portion of the season. It is a shade grass and yields well under shade conditions and usually remains green

TABLE 1.—*Growth and consumption of Kentucky bluegrass for 1935, 1936, and 1937.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
	1935		
Apr. 26	1,824	28	0
May 24	961	42	825
June 21	1,229	61	893
July 19	1,351	83	643
Aug. 13	445	90	500
Sept. 11	695	—	1,402
Total	6,505	—	4,263
	1936		
Apr. 24	876	25	0
May 22	1,435	62	532
June 19	509	84	582
Aug. 1	−128	—	1,267
Aug. 29	463	94	461
Sept. 26	228	—	70
Total	3,383	—	2,912
	1937		
May 4	880	18	0
June 1	1,469	48	293
July 20	909	66	509
Sept. 3	928	85	2,825
Nov. 15	721	—	1,282
Total	4,908	—	4,908

under moderate drouth conditions. Consumption is rather uniform throughout the grazing season, particularly if the season is dry or approximately normal. An abnormally wet season causes the growth to be large and stemmy, thus lowering consumption. Consumption in 1935 was 90% of production, but in 1936 it was approximately 99%. In 1937 it was 93%. If these figures are a criterion, then orchard grass must be relatively palatable. Fig. 4 illustrates the growth and consumption trends. Table 2 presents the growth and consumption data in tabular form.

In 1935, 76% of the total yields occurred before July 20. The total yield for the season was slightly less than that of bluegrass, but like bluegrass its productivity is greatest in the cool fore part of the growing season. As previously stated, orchard grass begins growth early in the spring and matures shortly after Kentucky bleugrass. In 1936 the effect of heat and drouth are distinctly apparent, particularly as it has affected productivity, but the percentage of the total yield on any given date approximates that of the previous year. The total yield for 1936, as well as 1937, exceeded that of Kentucky bluegrass,

a difference possibly attributal to temperature. As in 1935 and 1936 a high percentage of the total yield is accounted for previous to mid-July.

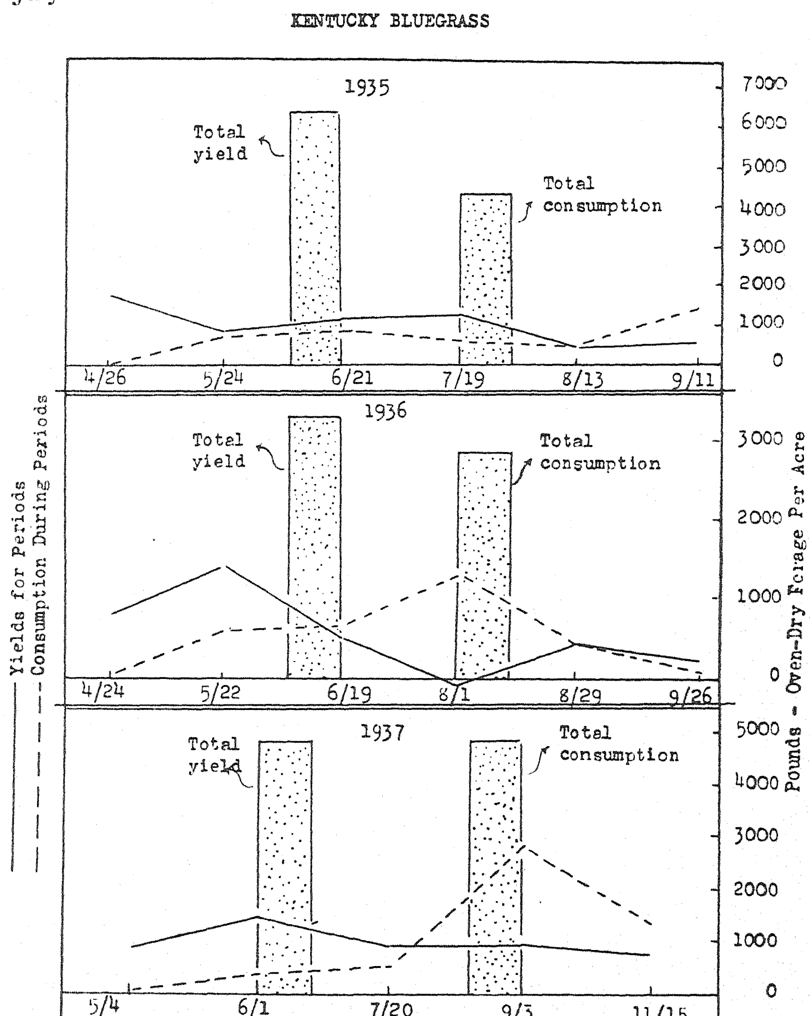

FIG. 3.—Graphs illustrating yields and consumption of Kentucky bluegrass for the years 1935, 1936, and 1937.

BROME GRASS

Brome grass, *Bromus inermis*, has been used in these experiments as a pasture for sheep since 1934, but yield and consumption data are presented only for 1935, 1936, and 1937.

Considerable interest has been evinced in this grass not only because of its yielding ability but because of its apparent palatability and nutritiousness. It has proved to be drouth and heat resistant under Urbana conditions, remaining green and palatable in 1936

TABLE 2.—*Yield and consumption of orchard grass, Dactylis glomerata, in 1935, 1936, and 1937.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
	1935		
Apr. 26	1,799	31	0
May 24	1,676	43	1,595
June 12	475	52	388
July 19	1,396	76	1,678
July 26	613	87	608
Aug. 23	100	88	—
Sept. 17	236	93	—
Oct. 15	426	—	852
Total	5,721	—	5,079
	1936		
May 27	1,897	49	0
June 26	699	67	931
July 21	−47	—	920
Aug. 24	641	83	1,010
Sept. 25	261	90	508
Nov. 11	601	—	615
Total	3,864	—	3,804
	1937		
May 4	1,236	23	0
June 7	2,379	67	576
July 1	427	75	1,096
July 29	925	92	992
Aug. 16	146	93	648
Sept. 15	458	—	277
Oct. 23	−208	—	1,469
Total	5,371	—	5,009

when Kentucky bluegrass became dormant and orchard grass was apparently unpalatable. The consumption in 1935 was 90% of the yields and likewise in 1936. The number of sheep pastured on the brome grass field in 1936 was reduced to prevent over-grazing and injury to the grass. In 1937 the consumption data are not complete. The sheep grazing this field were being used as part of a comparative test and were removed between July 29 and October 30, after which a number of Hereford cattle grazed until November 17. Consumption was 79% of yields, but it can be assumed that the long period of disuse in September and October accounts for this rather low consumption. Yield and consumption data are tabulated in Table 3. Fig. 5 illustrates the data by means of graphs.

Seasonal productivity of brome grass is similar to that of bluegrass and orchard grass. However, the seed matures considerably later than that of either of the former species. In 1935 the productivity on June 21 was 67% of the seasonal total. In 1936, on approximately the same

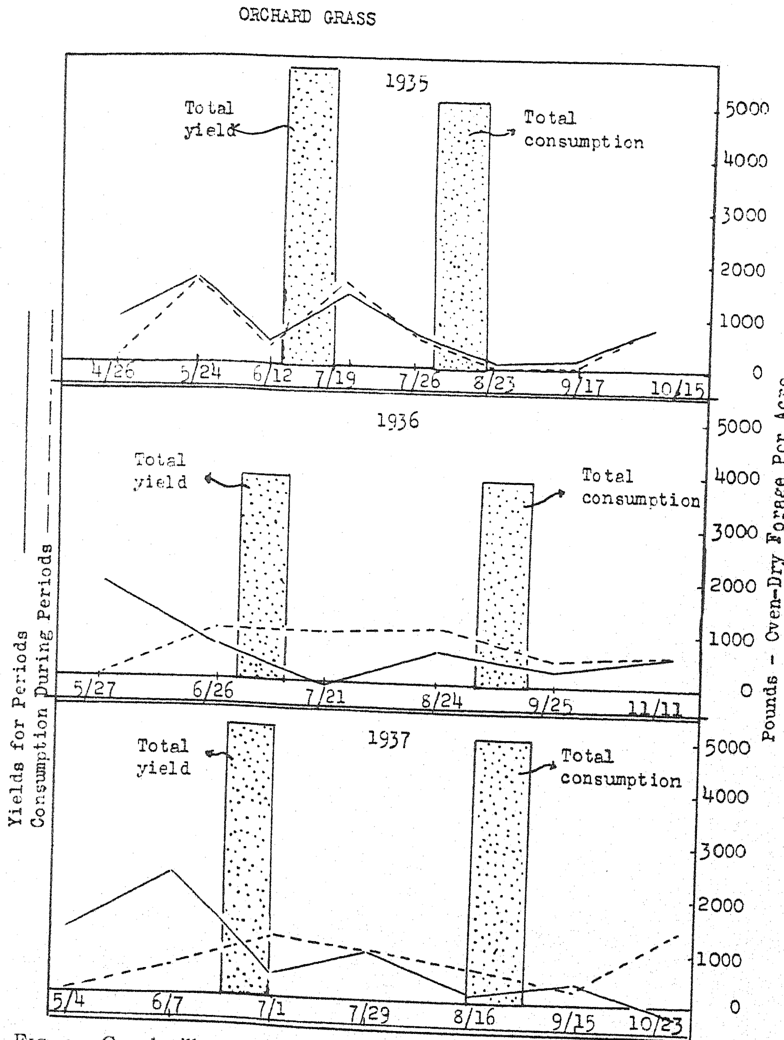

FIG. 4.—Graphs illustrating yield and consumption of orchard grass, *Dactylis glomerata*, in 1935, 1936, and 1937.

date it was 81% of the total, but in 1937 it was 73% of the total on July 1. The table gives some indication of the much greater productivity of brome grass. The percentages of the total production, particularly in 1936, also show that after July 1 the high temperatures

and lack of rainfall had a restraining effect upon yield or growth as the balance of the grazing season produced only 19% of the seasonal total.

TABLE 3.—*Yield and consumption of brome grass, Bromus inermis, during the growing seasons of 1935, 1936, and 1937.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
	1935		
May 3	2,196	23	0
May 24	1,642	41	1,392
June 21	2,416	67	1,764
July 19	1,381	82	1,654
Aug. 30	1,450	98	2,108
Sept. 27	188	—	1,590
Total	9,273	—	8,508
	1936		
May 1	1,252	26	0
May 26	1,579	59	0
June 26	1,045	81	301
July 21	−468	—	1,428
Aug. 24	894	90	1,433
Sept. 15	457	—	1,233
Total	4,759	—	4,395
	1937		
May 4	1,194	17	0
June 8	3,118	59	1,976
July 1	913	74	596
July 29	1,717	98	1,645
Aug. 16	184	99	0
Oct. 30	133	99	0
Nov. 17	−194	—	1,355
Total	7,066	—	5,572

REED CANARY GRASS

Reed canary grass has usually been considered to be best adapted to low land subject to periodic overflow. In the spring of 1934 a 5-acre field was seeded to reed canary grass. This field has approximately the same elevation as the surrounding farm land. It was used as a pasture for cows in 1935, and for pasturing Hereford steers in 1936 and 1937. Yield data are available for the latter years (Table 4).

Yield curves (Fig. 6) are similar to those of orchard grass and bluegrass in that a large percentage of the yield is produced early in the season and it is during this period that the grass is most palatable. However, the cattle were not turned in this pasture until May 26, 1936.

The results in terms of consumption have come largely in July and August at the time when reed canary grass is considered less palatable.

In 1936 it furnished a large quantity of forage when other pastures were not productive. However, a large percentage of this forage was carried over from the preceding months. In 1937 cattle were not

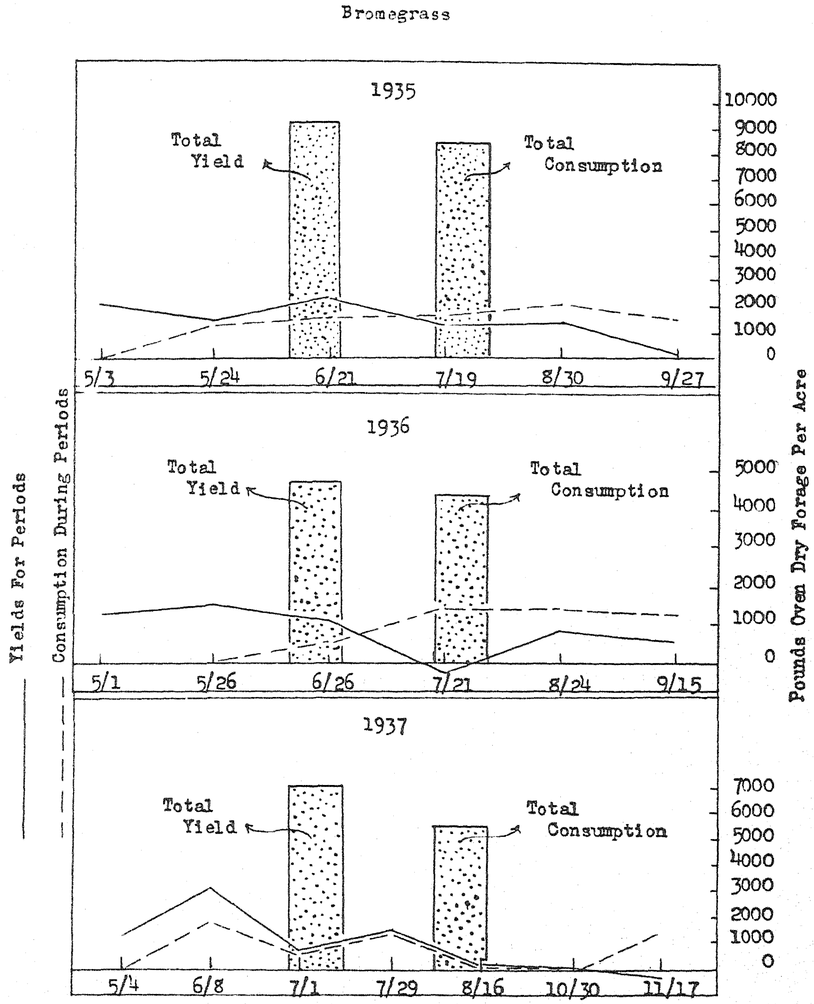

FIG. 5.—Yields and consumption of brome grass, *Bromus inermis*, during growing seasons of 1935, 1936, and 1937.

turned into the canary grass until June 23. The trend of production paralleled that of 1936, however consumption in 1937 was very low. This is presumably the result of previous management of the livestock, although any one of a number of factors may be responsible for this decline.

TABLE 4.—*Yield and consumption of reed canary grass, Phalaris arundinacea, in 1936 and 1937.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
	1936		
May 26	2,323	43	0
June 26	1,364	68	-451
July 21	194	72	2,400
Aug. 24	859	88	1,390
Sept. 15	663	—	504
Total	5,403	—	3,843
	1937		
May 4	1,000	22	0
June 17	2,390	77	0
June 23	512	89	0
July 16	1,161	—	405
Aug. 13	-446	—	679
Sept. 13	539	—	-558
Oct. 30	-773	—	1,346
Total	4,385	—	1,872

ALFALFA

The results of the grazing period of 1935 were available and are included (Table 5) because they show some rather interesting points.

TABLE 5.—*Yield and consumption of alfalfa in the grazing season of 1935.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
May 3	2,550	26	0
May 24	996	36	909
June 21	1,647	53	2,206
July 19	1,157	65	1,834
Aug. 30	2,667	93	2,331
Sept. 27	638	—	1,351
Total	9,655	—	8,631

Yields were high as well as consumption, but it should be noted that the yields and consumption were rather uniformly distributed throughout the growing season. This is in contrast to the fluctuating yields of the grasses. The grasses produce a larger proportion of their annual yield in the first two months of the grazing period than does alfalfa. The grasses are for the most part cool weather plants and are adapted to greater productiveness during the cool portion of the grazing season. As temperature increases grass production tends to decrease. Temperature is apparently more important than moisture, especially during the fore part of the grazing season. This is true of

the later months of the grazing season also, but during this latter period moisture is equally important. However, alfalfa as is illustrated in Fig. 7, produced approximately one-half of its total growth at the mid-season grazing point.

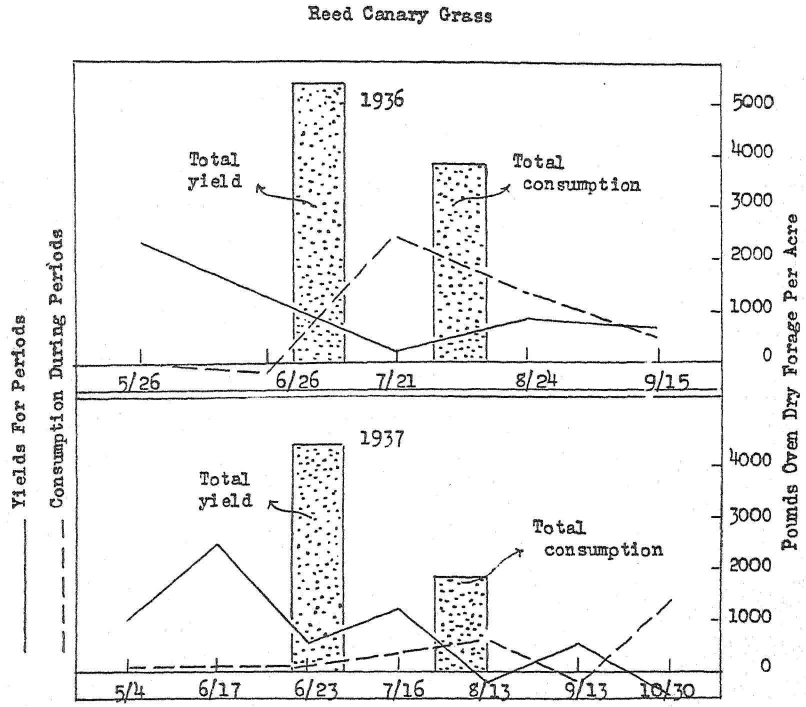

FIG. 6.—Yields and consumption of reed canary grass, *Phalaris arundinacea*, for growing seasons of 1936 and 1937.

SUMMARY

Data are presented showing calculated yields and consumption of pasturage at Urbana, Illinois.

The yield curves of pasture grasses parallel rather closely precipitation curves but are the reverse of temperature curves; when temperature increases the tendency for grass yields is to decrease. Alfalfa is rather uniformly productive throughout the grazing season.

Kentucky bluegrass has been used frequently as a basis of comparison with other grasses, and although it may have some serious defects, there is little likelihood that it can be equalled for general adaptation, utility, and persistence.

Brome grass persistently out-yielded all the other grasses used for pasturage at this station during 1935, 1936, and 1937. It apparently has a high degree of palatability as indicated by a comparison of the curves of consumption and production. In addition to its yielding capacity and apparent palatability, it has persisted remarkably well.

October, 1937, and it was found that on the treated area approximately three times as much growth had developed as on the untreated portion. The most striking vegetational change, however, was in the

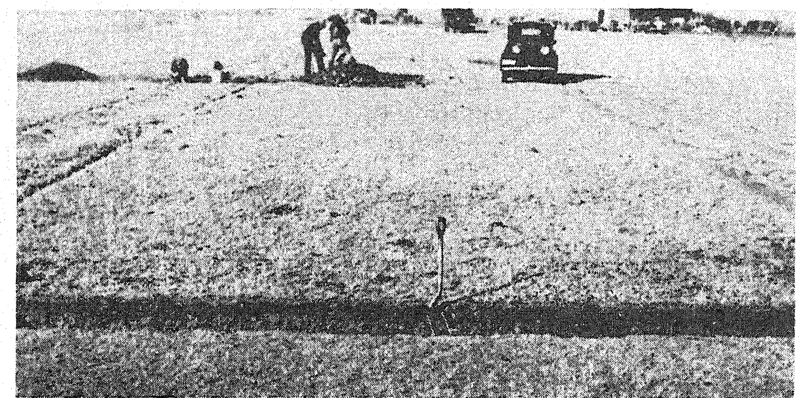

FIG. 1.—Profile of heavy clay loam soil on Hereford Project showing shallow penetration of moisture on an untreated area. Three inches of water applied in 1 hour by an artificial rainfall apparatus resulted in a runoff loss of almost 2 inches.

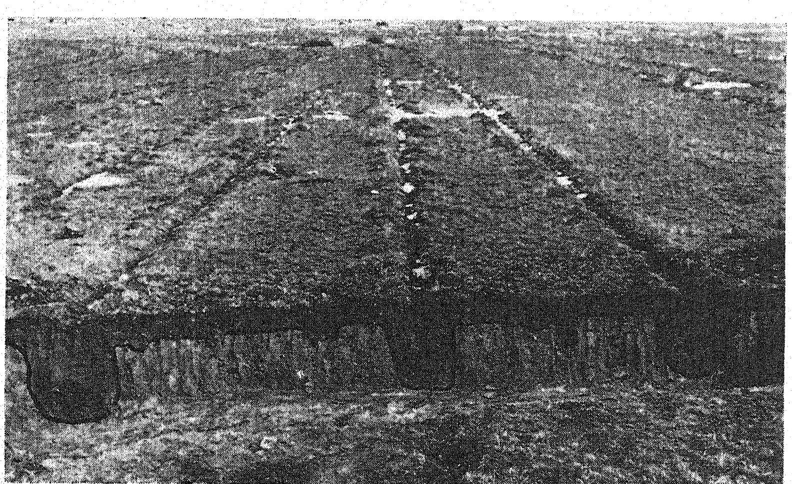

FIG. 2.—Profile of a heavy clay loam soil on Hereford Project showing effect of furrowing on moisture penetration. The furrows were 8 x 4 inches placed 7 feet apart. This system retained 2 inches of 3 inches of water applied in 1 hour by means of an artificial rainfall apparatus.

composition of the cover. Sand blue-stem, *Andropogon hallii,* is relatively abundant at the present time on the treated portion, whereas no sand blue-stem is found on the untreated area; side-oats grama,

Bouteloua curtipendula, was more conspicuous, with blue grama, *Bouteloua gracilis*, less so. The changes that have occurred indicate a rather strong trend toward the original type of vegetation that formerly occupied the soils of the region.

To date small furrows varying from 4 to 8 inches wide and 4 to 8 inches deep have given the quickest and heaviest vegetational response in Region Six of the Soil Conservation Service. On the project at Hereford, Texas, a pasture was furrowed the latter part of April, 1937. A three-row lister, with the middle beam removed, was used to make pairs of furrows which were spaced 14 feet apart. The moldboards of the lister were removed, the points clipped, and the beams adjusted to make a furrow approximately 8 inches wide and 4 inches deep. Runoff studies made with an artificial rainfall apparatus showed that this type of furrow placed 7 feet apart on a clay loam soil of 3% slope was capable of holding 2 inches of a 3-inch rain applied in 1 hour when the soil was dry at the beginning of the test. An adjacent untreated area lost 2 inches of the three applied. The two plats were cross-sectioned 48 hours after the water was applied and photographs made of the distribution of moisture in the soil. As shown in Figs. 1 and 2, the moisture penetrates deeply in the furrow and forms a reservoir upon which adjacent growing plants may feed, while penetration is uniformly shallow on non-furrowed land. Small, closely spaced furrows tend to distribute soil moisture more evenly, and therefore give quicker revegetation of the disturbed area, together with increased production of grass.

To measure accurately the effectiveness of these furrows, grass was harvested from representative areas on both the furrowed and unfurrowed portions of the pasture. Data were taken the first week in October, 1937. Harvesting was done by hand in such a manner as to simulate close grazing. The yield on the furrowed portion was at the rate of 1,761 pounds of air-dried grass per acre and on the unfurrowed, 704 pounds per acre. This was an increase of 1,057 pounds per acre.

On the Cheyenne Wells Project, furrows 5 inches wide, 4 to 5 inches deep, and 4 feet apart were constructed in April, 1937 (Fig. 3). Runoff studies on these treated areas showed that they retained 70% more water out of 3 inches applied in 1 hour by an artificial rainfall apparatus than an adjacent untreated area. Moisture tests made in September indicated 1.4 inches more soil-stored water in the treated plat. Rainfall was only 7.36 inches during the period of April to September.

Measurements made in October on the treated area showed an average density of 9.48% for buffalo-grama and 0.17% for forbs, while on the untreated range there was an average density of 4.8% for buffalo-grama and 0.54% for forbs (Fig. 4).

State and federal experiment stations are conducting similar investigations. Contour listing of native grassland was started at the Texas Agricultural Experiment Station at Spur, Texas, in 1932, and extended in 1934 and 1936.[5] The original work in 1932 was done on a

[5]Data concerning the Spur studies were supplied by R. E. Dickson, Superintendent, and B. C. Langley, Technician, Texas Agricultural Experiment Station, Spur, Texas.

typical west Texas pasture lot where prickly pear, mesquite brush, and weeds had largely replaced the nutritious grasses. Results show that the yield, stand, and palatability of the forage have been in-

FIG. 3.—Type of pasture and range land treated in the spring of 1937 on the demonstrational project near Cheyenne Wells, Colorado.

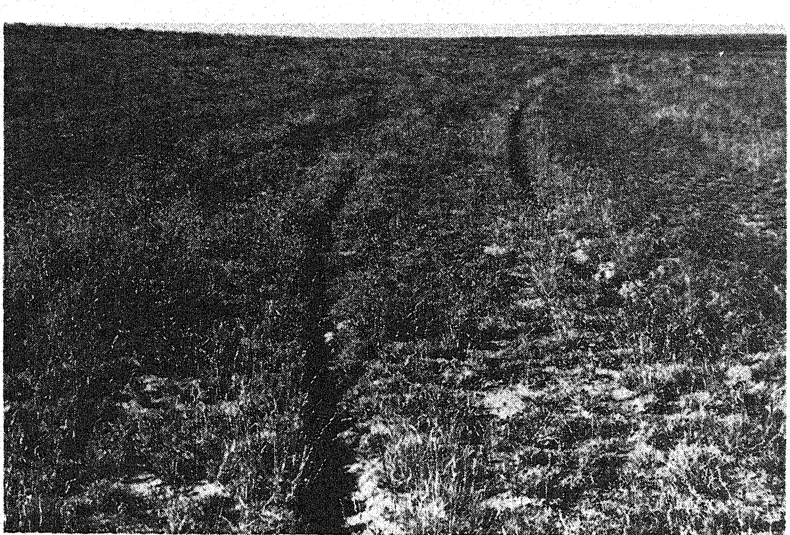

FIG. 4.—Vegetational response as a result of trench furrowing pasture and range lands near Cheyenne Wells, Colorado.

creased by listing. At present the more important grass species are buffalo, blue grama, purple three-awn, and tobosa, the latter two species having decreased in density while the former two have in-

creased. Prior to listing, blue grama occurred only to a limited extent. The effect of contour listing on yield per acre of native grass pasturage is shown by the fact that there was an average of 2,369 pounds of air-dried hay per acre on listed land and only 725 pounds on unlisted land.

Other interesting observations at the Spur station are as follows: (1) The forage on the contour-listed areas was more palatable, as indicated by the more luxuriant growth; (2) fewer forbs occurred on areas where a good stand of grass has become re-established; (3) heavy rains in September, 1936, increased the total yield of forage about 20%.

In Region Six it has been noted that livestock generally graze along the furrow, and that the grasses stay green longer in and around the furrows than in the untreated portions. If furrowing is done in the fall there will be more weeds along the furrow than if treatment is made in the spring. Grasses give the best response when the range is furrowed in the spring. In some cases it appears that grasses have a tendency to crowd weeds from the furrows the second growing season. On sharp ridges above a foot in height there is a slower recovery of the more desirable grasses, due to the rapid drying out of the topsoil and unfavorable position for retention of runoff on the ridge.

RESPONSE OF CERTAIN PERENNIAL GRASSES TO CUTTING TREATMENTS[1]

C. M. HARRISON AND C. W. HODGSON[2]

IN the management of perennial grasses for forage purposes, it is important to know the effects of partial and complete defoliation upon the yield of top growth and upon the root development of these grasses. While grasses do not respond in precisely the same manner to grazing in the field by animals as they do to clipping in the greenhouse, results of such clipping trials furnish a valuable indication as to how the grasses may respond to varying amounts of defoliation under grazing practices. The present paper deals with the effects of weekly cutting at different heights on the yields of tops and underground parts by some of the more common perennial grasses in Michigan.

Frequent and close clipping of the tops of a grass reduces the amount of roots produced and the total yield of tops. When grass plants are completely defoliated, new top growth is initiated, in a large measure, at the expense of previously deposited root reserves. Unless these reserves are sufficiently replenished during the periods between successive cuttings, a reduction in reserve content of the roots occurs, which progressively diminishes the amount of new top and root growth following each cutting to the point of extinction.

Dexter (2),[3] Graber (3, 4), Graber, *et al.* (5), Harrison (6, 7), Leukel and Coleman (8), Leukel, *et al.* (9), Mortimer and Ahlgren (10), Pierre and Bertram (11), Robertson (12), Sprague (14), and Sturkie (15) give the effects of various cutting treatments on the yields of tops and underground parts of quack grass (*Agropyron repens*), Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis alba*), fescue (*Festuca rubra fallax*), timothy (*Phleum pratense*), Colonial bent grass (*Agrostis tenuis*), Bahai grass (*Paspalum notatum*), Centipede grass (*Eremochloa ophiuroides*), Carpet grass (*Axonopus compressus*), Kudzu (*Pueraria thunbergiana*), blue grama (*Bouteloua gracilis*), Junegrass (*Koeleria cristata*), Porcupine grass (*Stipa spartea*), smooth bromegrass (*Bromus inermis*), Sudan grass (*Andropogon sorghum*), seaside (*Agrostis palustris*) and velvet bent grasses (*Agrostis canina*), and Johnson grass (*Sorghum halepense*). Sampson and Malmsten (13) studied the effects of frequency of cutting on some of the western range grasses, and Biswell and Weaver (1) give the response of some prairie grasses to frequent clipping. Several of the papers cited present good literature reviews on the subject.

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[1]Joint contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Journal Article No. 347 (new series) of the Michigan Agricultural Experiment Station. Received for publication January 16, 1938.

[2]Research Associate in Farm Crops, Michigan Agricultural Experiment Station; and Agent, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 429.

MATERIALS AND METHODS

The present experiment was conducted in the greenhouse at the Michigan State College, East Lansing, Mich. Orchard grass (*Dactylis glomerata L.*), timothy (*Phleum pratense*), quack grass (*Agropyron repens*), Kentucky bluegrass (*Poa pratensis*), smooth brome grass (*Bromus inermis*), and a mixture of smooth brome grass and alfalfa were used. The plants were set out in 10-inch clay pots on October 9, 1936, using quartz sand instead of soil. For each of the five grass species used, 23 pots were each planted with eight vegetative segments collected from field plats, while four brome grass segments along with four alfalfa plants, about three months old, were set out in each of the pots containing the alfalfa and brome grass mixture. All plants were watered and supplied with a nutrient solution to secure the best growth under winter greenhouse conditions.

The nutrient solution contained the following concentrations and was applied once or twice per week:

Nutrient	Partial volume molecular concentration
KH_2PO_4	0.0045
$Ca(NO_3)_2 \cdot 4H_2O$	0.0090
$MgSO_4 \cdot 7H_2O$	0.0045

A trace of iron sulfate ($FeSO_4$) was added to the solution from time to time when the plants appeared to need iron.

The greenhouse temperature ranged between 70° and 80° F, except during the sunny days of May, when it occasionally went as high as 90° to 100°. The intensity of light and length of day in the greenhouse depended largely upon the weather conditions which were more or less cloudy during the winter, with about 50% of the days clear in the spring. No artificial light was used.

The plants were grown until March 29, at which time they had reached approximately the early bloom stage and the plants in three cultures of each set were washed out and green and dry weights determined for the tops and roots. These were used as the "initial checks".

The remaining cultures of orchard grass, timothy, quack grass, and brome grass were arranged in sets of five and were cut at 1 inch, 3 inches, and 6 inches above the sand, with one set of each species being left uncut to be washed out at the end of the trial and used as "final checks". Two sets of the alfalfa-brome grass cultures were cut at 1 inch and 6 inches, respectively, while another set was cut and gradually brought down to 2 inches in four cuttings and thereafter cut at 2 inches. One set was left as final checks. In the bluegrass series, the cutting treatments were ½ inch, 2 inches, 3 inches, and final checks.

The method of cutting consisted of raising all of the leaves of the plants and cutting them, along with the stems, back to the designated length.

Cutting began on March 30 and was repeated each week until May 26, 1937, when all plants were washed out, the tops separated from the roots, and green and dry weights taken. Green and dry weights were also determined each week for that portion of the tops removed.

EXPERIMENTAL RESULTS

YIELDS OF TOP GROWTH

Table 1 gives the average yields per culture in dry weight of top growth by the various species at the different heights of cutting.

The column labeled "total weight minus initial and last weights" gives the yields produced during all but the last week of the cutting period. During this period, orchard grass cultures cut at 1 inch, 3 inches, and 6 inches yielded 4.37, 16.65, and 23.09 grams, respectively. The yields of top growth produced by those orchard grass plants cut at 1 inch decreased steadily and quite rapidly from 2.3 grams during the first week of the period to 0.01 gram during the week ending May 19. The plants cut at 3 inches yielded 3.9 grams of dry weight during the first week, while those cut at 6 inches yielded 2.9 grams during the same period. Following a drop in production to 2.53 grams during the second week, the yields produced by the 3-inch cultures remained reasonably constant. The weekly yields of tops from the 6-inch cultures remained fairly constant at a level slightly above that of the 3-inch cultures.

The total yields of orchard grass tops were 22.51, 74.25, and 90.09 grams, respectively, by those plants cut at 1 inch, 3 inches, and 6 inches. The initial checks yielded 37.0 grams and the final checks 124.0 grams per culture. These results show that total yield of tops varied inversely with the severity of cutting treatment. The steady decline in the weekly yields of top growth by the cultures cut at 1 inch indicates that these plants were steadily using up their food reserves and did not have sufficient leaf surface remaining to manufacture the food necessary for a large growth. Cutting to 1 inch practically defoliates "high growing" grasses like orchard grass.

The difference between the initial weight of tops from the 1-inch cultures and that of the initial checks represents, approximately, the dry weight left in the lowest 1 inch of the tops. In the case of the 1-inch cultures, most of this original 1 inch was sloughed off and the yield of new growth was not enough to equal this loss.

Timothy behaved similarly to orchard grass, except that the yields of timothy were generally less than the corresponding yields of orchard grass. The total yields of timothy during all but the last week of the cutting period were 2.61, 8.83, and 15.33 grams, respectively, by the cultures cut at 1 inch, 3 inches, and 6 inches, showing that the amount of recovery growth varied inversely with the severity of cutting treatment.

The total yields of quack grass were about one-third to one-half as large as were those of the corresponding orchard grass cultures. The quack grass plants cut at 1 inch appeared to adapt themselves better to this severe treatment than did orchard grass and timothy. The average yield by the 1-inch cultures during the first week was 0.83 gram for quack grass and 2.3 grams for orchard grass; during the week ending May 19, quack grass yielded 0.23 gram and orchard grass, 0.01 gram. The weekly yields of quack grass from the 3-inch and the 6-inch cultures had about the same general trends as those of orchard grass receiving corresponding treatments.

The total dry weight of tops produced by the brome grass plants at 1 inch was 16.92 grams per culture, which was approximately equal to the dry matter in the initial check. The average total yield (47.21 grams) from the 6-inch cultures was approximately equal to that from the final check, which was 47.8 grams. These results indicate that

brome grass was less injured by the clipping treatments than were orchard grass and timothy because the 1-inch cultures of the latter yielded less dry weight of tops than the initial checks and the 6-inch cultures yielded less than the final checks.

It will be noted, however, that, in general, brome grass produced lower yields than did orchard grass or timothy receiving corresponding treatments. This may be partly accounted for by the fact that the entire set of brome grass cultures was located in a shadier part of the greenhouse than were the other grasses.

The brome grass cultures cut at 3 inches produced slightly more top growth during the first two weeks of the cutting period than did those cut at 6 inches. The yields by the plants cut at 3 inches were 2.46 and 1.51 grams, respectively, for the first and second weeks, compared with 2.26 and 1.21 grams from those cut at 6 inches. Beginning with the third week the 6-inch cultures yielded more than the 3-inch cultures.

The results obtained for the alfalfa-brome grass mixture indicate that brome grass was benefited by its association with alfalfa, especially when the plants were kept short. There were only one-half as many brome grass segments in each culture of the mixture as in each of the straight brome grass cultures. Nevertheless, the average yields per culture by the brome grass plants in the mixture cut at 1 inch were 0.33, 0.34, and 0.23 gram of dry weight, respectively, for the last three cuttings, compared with 0.16, 0.08, and 0.08 gram by the corresponding straight brome grass cultures.

The figures for bluegrass indicate that this grass could be maintained under the conditions of this experiment even when cut weekly at only ½ inch above the sand. The weekly yields from the ½-inch cultures declined at first but soon leveled out and remained approximately the same thereafter. The average total yield by the ½-inch cultures was 20.89 grams, which was 3.69 grams more than the dry matter harvested from the initial check. There were no essential differences between the weekly or the total yields of the bluegrass plants cut at 2 inches and those cut at 3 inches. The average total yield of the 2-inch cultures was 34.64 grams, while that of the 3-inch cultures was 36.25. The total yield during the cutting period, except for the last week, was 6.84 grams for the plants cut at 2 inches and 6.85 grams for those cut at 3 inches.

ROOTS AND RHIZOMES

The dry weight of roots in each culture and the average per culture for the various treatments are given in Table 2. Fig. 1 shows that the amount of roots produced by timothy decreased with increase in severity of cutting treatment. This behavior was also typical of the other grasses.

The average dry weight of roots in the orchard grass initial check cultures was 13.1 grams. By the end of the cutting period, the plants in four of the 1-inch cultures were dead, and the dry weight of roots in the other 1-inch culture was only 0.75 gram. The final check cultures averaged 30.8 grams of roots at the end of the same period.

TABLE 1.—*Average yield of tops per pot in grams of dry weight.*

Treatment	Initial weight Mar. 31	Cutting dates							Washed out May 26	Total weight minus initial and last weights	Total
		Apr. 7	Apr. 14	Apr. 21	Apr. 28	May 5	May 12	May 19			
Orchard Grass											
Cut at 1 in.	17.9	2.3	1.14	0.54	0.29	0.06	0.03	0.01	0.24	4.37	22.51
Cut at 3 in.	13.4	3.9	2.53	2.22	1.91	1.79	2.25	2.05	44.2	16.65	74.25
Cut at 6 in.	5.3	2.9	3.06	3.66	3.56	3.51	3.76	2.64	61.7	23.09	90.09
Check (initial)	37.0	—	—	—	—	—	—	—	—	—	37.0
Check (final)	—	—	—	—	—	—	—	—	124.0	—	124.0
Timothy											
Cut at 1 in.	11.1	1.16	0.60	0.42	0.25	0.12	0.04	0.02	1.7	2.61	15.41
Cut at 3 in.	7.3	1.76	1.27	1.14	1.11	1.40	1.02	1.13	16.3	8.83	32.43
Cut at 6 in.	4.8	1.80	2.12	2.07	2.24	2.45	2.34	2.31	39.7	15.33	59.83
Check (initial)	23.7	—	—	—	—	—	—	—	—	—	23.7
Check (final)	—	—	—	—	—	—	—	—	76.8	—	76.8
Quack Grass											
Cut at 1 in.	8.3	0.83	0.68	0.62	0.47	0.30	0.25	0.23	1.1	3.38	12.78
Cut at 3 in.	6.6	1.24	0.90	0.78	0.75	0.78	0.83	0.75	10.0	6.03	22.63
Cut at 6 in.	4.0	0.95	0.96	0.98	0.92	1.11	1.06	1.08	21.1	7.06	32.16
Check (initial)	14.5	—	—	—	—	—	—	—	—	—	14.5
Check (final)	—	—	—	—	—	—	—	—	62.4	—	62.4
Brome Grass											
Cut at 1 in.	12.9	1.75	0.87	0.47	0.35	0.16	0.08	0.08	0.26	3.76	16.92
Cut at 3 in.	10.9	2.46	1.51	1.24	1.17	1.11	1.27	1.45	9.6	10.21	30.71
Cut at 6 in.	5.8	2.26	1.21	1.81	2.02	2.57	2.40	2.64	26.5	14.91	47.21
Check (initial)	16.7	—	—	—	—	—	—	—	—	—	16.7
Check (final)	—	—	—	—	—	—	—	—	47.8	—	47.8

Bluegrass											
Cut at ½ in.	15.1	1.08	0.72	0.54	0.54	0.44	0.48	0.49	1.5	4.29	20.89
Cut at 2 in.	10.6	1.31	0.89	0.91	0.74	0.87	1.08	1.04	17.2	6.84	34.64
Cut at 3 in.	7.7	1.26	0.70	0.78	0.85	1.12	1.08	1.06	21.7	6.85	36.25
Check (initial)	17.2	—	—	—	—	—	—	—	—	—	17.2
Check (final)	—	—	—	—	—	—	—	—	51.9	—	51.9
Alfalfa and Brome Grass											
Cut at 1 in:											
Alfalfa	9.9	0.82	1.02	0.93	0.52	0.53	0.45	0.37	2.9	4.64	17.44
Brome grass	9.2	0.33	0.52	0.40	0.27	0.33	0.34	0.23	0.7	2.42	12.32
Cut at 6 in.:											
Alfalfa	5.8	0.84	1.09	1.14	1.05	1.04	1.14	1.05	14.2	7.35	27.35
Brome grass	2.5	0.86	0.96	0.87	1.31	1.49	1.26	1.84	28.1	8.59	39.19
Cut at 2 in. (gradually):											
Alfalfa	1.1	1.01	1.71	2.8	0.21	0.86	0.87	0.66	4.2	8.12	13.42
Brome grass	2.6	2.68	3.55	9.6	1.57	1.24	1.71	1.60	8.9	21.95	33.45
Check (initial):											
Alfalfa	3.8	—	—	—	—	—	—	—	—	—	3.8
Brome grass	7.1	—	—	—	—	—	—	—	—	—	7.1
Check (final):											
Alfalfa	—	—	—	—	—	—	—	—	18.2	—	18.2
Brome grass	—	—	—	—	—	—	—	—	47.8	—	47.8

TABLE 2.—*Dry weight of roots per pot, in grams.*

Treatment	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Av.
Orchard Grass						
Check (initial)	11.5	11.0	16.8	—	—	13.1
Cut at 1 in.	0.75	dead	dead	dead	dead	0.75
Cut at 3 in.	9.4	9.2	9.9	9.8	10.4	9.7
Cut at 6 in.	18.5	17.4	18.1	17.6	19.7	18.3
Check (final)	32.9	26.3	32.6	34.6	27.4	30.8
Timothy						
Check (initial)	5.5	6.0	7.0	—	—	6.2
Cut at 1 in.	0.16	0.17	0.94	0.82	dead	0.52
Cut at 3 in.	3.53	5.34	4.0	5.0	2.9	4.15
Cut at 6 in.	4.8	5.8	7.8	5.5	7.0	6.2
Check (final)	17.3	19.4	9.1	15.4	8.1	13.9
Quack Grass						
Check (initial)	12.2	3.8	5.6	—	—	7.2
Cut at 1 in.	2.4	0.6	0.6	1.8	1.3	1.3
Cut at 3 in.	2.1	3.4	2.8	2.4	2.2	2.6
Cut at 6 in.	2.6	6.5	4.6	3.5	5.1	4.5
Check (final)	7.1	5.3	4.3	3.4	3.9	8.9
Brome Grass						
Check (initial)	10.7	13.5	11.0	—	—	11.7
Cut at 1 in.	1.8	0.44	1.3	0.55	1.0	1.02
Cut at 3 in.	21.8	11.3	11.7	10.6	11.3	13.3
Cut at 6 in.	19.0	21.2	13.1	13.8	21.0	17.6
Check (final)	47.5	18.7	51.9	48.8	25.2	38.4
Bluegrass						
Check (initial)	16.5	6.6	7.0	—	—	10.0
Cut at ½ in.	4.1	5.3	4.2	5.1	3.3	4.4
Cut at 2 in.	8.2	8.7	3.6	6.0	4.7	6.2
Cut at 3 in.	4.5	8.4	6.7	5.4	6.2	6.2
Check (final)	8.5	8.9	10.0	5.9	5.6	7.8
Alfalfa (Brome)*						
Check (initial)	7.5	7.0	3.5	—	—	—
Cut at 1 in.	4.8	2.9	4.4	3.2	3.6	3.8
Cut at 6 in.	16.1	9.5	7.6	9.9	12.6	11.1
Cut gradually to 2 in.	6.8	4.9	3.5	6.7	5.4	5.5
Check (final)	25.4	11.3	5.9	13.2	19.8	15.1
Brome (Alfalfa)†						
Check (initial)	12.8	10.0	15.8	—	—	12.9
Cut at 1 in.	5.8	2.4	3.9	1.6	4.3	3.6
Cut at 6 in.	9.1	15.0	12.2	8.3	7.5	10.4
Cut gradually to 2 in.	11.0	15.3	8.8	11.3	11.7	11.6
Check (final)	24.6	36.4	53.1	36.6	42.9	38.7

*Alfalfa roots from the alfalfa brome mixture.
†Brome grass roots from the alfalfa brome mixture.

These results indicate that those plants cut at 1 inch used up practically all of their root reserves in producing new top growth. They were kept so nearly defoliated that they never had an opportunity to manufacture and store new supplies of reserve food. The plants cut

at 3 inches also showed a net loss, while those cut at 6 inches increased the weight of dry matter in their roots but not nearly as much as did the final checks.

In general, the timothy plants yielded considerably less dry weight of roots than did the corresponding orchard grass plants. The timothy cultures cut at 1 inch behaved in about the same manner as orchard

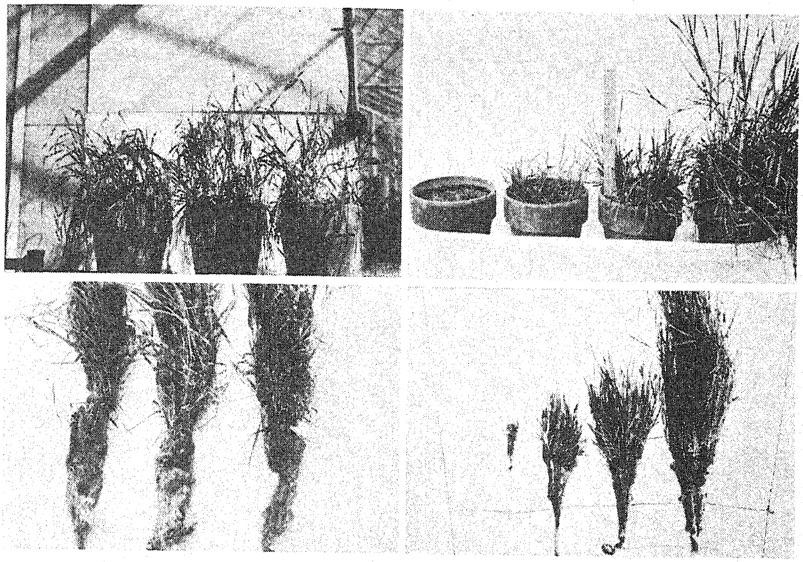

FIG. 1.—Timothy. *Upper left*, the initial checks taken at the beginning of the cutting period. *Lower left*, the initial checks after they had been removed from the pots and washed free of sand. Taken on the same day as the upper picture. Note the uniformity in the amount of roots per culture. *Upper right*, picture taken at the end of the cutting period. Reading from left to right, cultures cut at 1 inch, 3 inches, 6 inches, and final check. *Lower right*, picture of the same plants as above after they had been removed from the pots and washed free of sand. Note how the amount of roots per culture increases with decrease in severity of cutting treatment. The amount of roots in the 6-inch culture was approximately the same as in the initial checks but the latter were closer to the camera.

grass, except that in only one culture were all of the plants dead. The roots of the other four 1-inch cultures averaged only 0.52 gram per culture. The 3-inch cultures had an average of 4.15 grams of roots and those cultures cut at 6 inches averaged 6.2 grams, which was exactly the same as the initial check and 7.7 grams less than the final check.

Quack grass, smooth brome grass and Kentucky bluegrass have growth habits somewhat different from those of orchard grass and timothy. All three of the former produce rhizomes in addition to roots, when environmental conditions are favorable for the production of rhizomes. The dry weight of roots (Table 2) indicates that these three grasses were more adapted to close clipping than were orchard grass

and timothy, because the amounts of roots produced by the 1-inch quack grass and brome grass cultures and by the ½-inch bluegrass cultures were greater than those produced by the orchard grass and timothy cultures cut at 1 inch.

The quack grass plants cut at 1 inch, 3 inches, and 6 inches possessed roots that averaged 1.3, 2.6 and 4.5 grams per culture, respectively, at the end of the cutting period. The initial checks averaged 7.2 grams and the final checks 8.9 grams. All treatments resulted in some loss in root weight, except the final check which added only 1.7 grams.

The dry weights of rhizomes are given in Table 3. The quack grass cultures averaged 3.60, 5.30, 7.08, 15.60, and 49.70 grams, respectively, for the initial check, 1-inch clipping, 3-inch clipping, 6-inch clipping, and final check. The quack grass under all treatments showed some increase in rhizomes over those produced by the initial check. These results, together with the fact that all of the clipped cultures produced less roots than the initial check, indicate that quack grass may have produced rhizomes at the expense of its roots.

TABLE 3.—*Dry weight of rhizomes per pot in grams.*

Treatment	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Av.
			Quack Grass			
Check (initial)	3.8	2.0	5.0	—	—	3.60
Cut at 1 in.	3.0	4.5	8.5	6.0	4.5	5.30
Cut at 3 in.	7.0	9.5	6.5	6.4	6.0	7.08
Cut at 6 in.	15.5	17.0	14.0	17.0	14.5	15.60
Check (final)	54.5	47.5	48.0	43.0	55.5	49.70
			Brome Grass			
Cut at 6 in.	—	—	—	1.5	0.6	1.05
Check (final)	2.0	—	0.5	1.0	3.5	1.75
			Bluegrass			
Check (initial)	2.3	2.5	2.0	—	—	2.27
Cut at ½ in.	4.0	1.6	2.5	1.1	2.0	2.24
Cut at 2 in.	8.5	4.5	3.5	4.0	3.6	4.82
Cut at 3 in.	6.5	6.0	5.5	8.5	6.5	6.60
Check (final)	33.0	9.0	10.6	7.0	12.5	14.42
			Alfalfa (Brome)			
Cut at 1 in.	0.2	0.1	0.5	—	—	0.3
Cut at 6 in.	0.2	0.5	0.4	—	—	0.4
Cut gradually to 2 in.	0.8	0.4	0.8	—	0.5	0.6
Check (final)	2.5	8.0	6.0	5.5	9.0	6.2

Brome grass produced fewer rhizomes than quack grass and appeared less resistant to close clipping. None of the clipped brome grass plants, except those in pots Nos. 4 and 5 of the 6-inch cultures, produced rhizomes. The rhizomes of these two cultures weighed 1.5 and 0.6 grams, respectively. There were practically no rhizomes on the initial check brome grass plants, and only four of the final check cultures possessed rhizomes. The average dry weight of rhizomes on these four cultures was 1.75 grams.

The average dry weights of brome grass roots per culture (Table 2) were 1.02, 13.3, and 17.6 grams, respectively, for the 1-inch, 3-inch and 6-inch cultures, compared with 11.7 and 38.4 grams, respectively, for the initial and final checks. Table 2 shows that even those plants cut at 3 inches produced an increase in dry weight of roots over the initial checks and that all the of 1-inch cultures contained some living plants at the end of the cutting period. These results indicate that brome grass was more adapted to close clipping than were orchard grass and timothy.

Where brome grass was grown in pots with alfalfa, the dry weights of the brome grass roots (Table 2) averaged 12.9, 3.6, 10.4, 11.6, and 38.7 grams per culture, respectively, for the initial checks, the plants cut at 1 inch, those cut at 6 inches, those cut gradually to 2 inches, and the final checks.

Although there were no rhizomes on the initial checks of brome grass associated with alfalfa (Table 3), at least three cultures in each treatment contained rhizomes at the end of the cutting period. The final checks averaged 6.2 grams of rhizomes per culture compared with 1.75 grams where brome grass was grown alone. When one considers that there were only one-half as many original grass plants in each culture of the alfalfa and brome grass mixture as in the straight brome grass, these results definitely support the contention that the brome grass was benefited by its association with alfalfa.

Bluegrass behaved more nearly like quack grass than did brome grass. Because bluegrass produces considerable photosynthetic area close to the ground, it was cut at ½ inch, 2 inches, and 3 inches instead of 1 inch, 3 inches, and 6 inches. The extremely high weight of roots (Table 2) in pot No. 1 of the initial bluegrass checks raises the average initial check weight higher than it would otherwise be. Disregarding this culture, the average dry weight of roots per culture was 6.8 grams for the initial checks, 4.4, 6.2, and 6.2 grams, respectively, for the plants cut at ½ inch, 2 inches, and 3 inches, and 7.8 grams for the final checks. The data in Table 2 indicate that there was practically no difference between cutting bluegrass at 2 inches and cutting it at 3 inches insofar as root development was concerned, and also that bluegrass was not critically injured by cutting it as close as ½ inch above the sand.

The data for the average dry weight per culture of bluegrass rhizomes (Table 3) are 2.27 grams for the initial checks, 2.24, 4.82, and 6.60 grams, respectively, for the ½-inch, 2-inch, and 3-inch cultures, and 14.42 grams for the final checks. These results do indicate some difference, which may not be important, between the plants cut at 2 inches and those cut at 3 inches. The plants cut at ½ inch just about "held their own" insofar as rhizomes were concerned, while the final checks yielded considerably more dry weight of rhizomes than did any of the clipped plants.

GENERAL DISCUSSION

The foregoing experimental results are intended to supplement the information already available regarding the effects of clipping upon

the behavior of perennial grasses, particularly upon the yields of tops and underground parts.

All of the grasses used in the experiment are of economic importance in Michigan. Quack grass is considered a noxious weed, and information regarding its response to various cutting treatments should aid in developing methods for its control. Orchard grass, timothy, smooth brome grass, and Kentucky bluegrass are used, to a greater or less extent, as pasture grasses in Michigan and other states. While cutting does not exactly simulate grazing, it does give some indication as to how grasses may respond to different intensities of grazing.

Grasses require chlorophyll-bearing tissue in order to manufacture carbohydrates. After all of the green leaves have been removed from a grass plant, new growth is initiated at the expense of carbohydrates previously stored in some remaining part of the plant. The new growth begins to manufacture more carbohydrates, and, if more carbohydrates are manufactured than are required immediately for growth or other consumption, the excess is stored for future use. When the interval between successive removals of the photosynthetic tissue is so short that the plant does not have time to replace the stored carbohydrates that it used in producing the new growth, the reserve supply will gradually become depleted to a point where it will be a limiting factor in the amount of new growth made before the next cutting. From this point on the reserve supply of carbohydrates continues to decrease, and the amount of new growth produced between successive cuttings gets less and less until there are not enough reserve carbohydrates to initiate any new growth and death of the plant results.

If the grass plants are cut high enough so that some green leaf tissue remains, a smaller amount of the reserve carbohydrates may be used in producing the new growth. If the plants were cut still higher, they might not use any of the reserves in producing new growth and might even keep on storing some carbohydrates.

Bluegrass withstood close cutting better than the other grasses because, under the conditions of the present experiment, it produced the most green leaves below a height of 1 inch. In other words, it produced more photosynthetic tissue close to the sand than did any of the other grasses.

At the beginning of the cutting period the grass plants were relatively high in carbohydrates. (Nitrogen had been withheld from the plants for a few weeks in order to allow them time to store some carbohydrates). Cutting some of the grasses (orchard grass, quack grass, and brome grass) at 3 inches resulted in more new growth being produced during the first week of the cutting period than cutting them at 6 inches. The removal of more carbohydrates and carbohydrate-manufacturing tissue from the plants cut at 3 inches resulted in them having less carbohydrates in relation to the nitrogen present than those cut at 6 inches and may have made the relationship of carbohydrates to nitrogen in the plants cut at 3 inches more favorable for vegetative extension. After some of the reserve carbohydrates had been used, the proportion of carbohydrates to nitrogen in the plants cut at 3 inches was probably too low to produce the most favorable

conditions for vegetative extension. This resulted in the 3-inch cultures making less growth than the 6-inch cultures after the first or second week. The plants cut at 3 inches depleted their carbohydrate reserves more rapidly than those cut at 6 inches during the first week because they made more growth and also had less leaf tissue with which to manufacture carbohydrates. Consequently, since they used more carbohydrates and manufactured less, the plants cut at 3 inches depleted their reserves faster than those cut at 6 inches.

In the case of the plants cut at 1 inch, so much of the carbohydrates was removed by the first clipping that the amount of carbohydrates left in the plants in relation to the nitrogen present was probably too small from the beginning of the cutting period to produce the most favorable conditions for vegetative extension. Perhaps the plants could have been cut at some height above or below 3 inches at which they would have made more growth during the first week than they did when cut at 3 inches.

SUMMARY AND CONCLUSIONS

1. Orchard grass, timothy, smooth brome grass, quack grass, Kentucky bluegrass, and a mixture of smooth brome grass and alfalfa were grown in 10-inch clay pots in the greenhouse and cut weekly at three different heights.

2. There were differences between the various species in the amount of injury incurred by continuous close clipping. In this respect they rated in the following order, beginning with the one least injured: Kentucky bluegrass, quack grass, smooth brome grass, with timothy and orchard grass being about equal.

3. In nearly every case the greatest total yield of top growth was obtained from those plants that were allowed to go unclipped. In general, the shorter a given grass was cut, the less top growth it produced.

4. The greatest yields of underground parts (roots and rhizomes) were also obtained from the uncut plants. The yields of underground parts decreased with increase in severity of cutting treatment.

5. Smooth brome grass did better when grown in a mixture with alfalfa than when grown alone.

LITERATURE CITED

1. BISWELL, H. H., and WEAVER, J. E. Effects of frequent clipping on the development of roots and tops in the prairie sod. Ecology, 14:368–390. 1933.
2. DEXTER, S. T. Response of quack grass to defoliation and fertilization. Plant Physiol., 11:843–851. 1936.
3. GRABER, L. F. Competitive efficiency and productivity of bluegrass (*Poa pratensis L.*) with partial defoliations at two levels of cutting. Jour Amer. Soc. Agron., 25:328–333. 1933.
4. ————. Food reserves in relation to other factors limiting the growth of grass. Plant Physiol., 6:43–72. 1931.
5. ————, NELSON, N. T. LEUKEL, W. A., and ALBERT, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wis. Agr. Exp. Sta. Res. Bul. 80. 1927.
6. HARRISON, C. M. Effect of cutting and fertilizer applications on grass development. Plant Physiol., 6:669–684. 1931.

7. ————. Responses of Kentucky bluegrass to variations in temperature, light, cutting, and fertilizing. Plant Physiol., 9:83–106. 1934.
8. LEUKEL, W. A., and COLEMAN, J. M. Growth behavior and maintenance of organic foods in Bahai grass. Fla. Agr. Exp. Sta. Bul. 219. 1930.
9. ————, CAMP, J. P., and COLEMAN, J. M. Effect of frequent cutting and nitrate fertilization on the growth behavior and relative composition of pasture grasses. Fla. Agr. Exp. Sta. Bul. 269. 1934.
10. MORTIMER, G. B., and AHLGREN, H. L. Influence of fertilization, irrigation and stage and height of cutting on yield and composition of Kentucky bluegrass (*Poa pratensis L.*).
11. PIERRE, W. H., and BERTRAM, F. E. Kudzu production with special reference to influence of frequency of cutting on yields and formation of root reserves. Jour. Amer. Soc. Agron., 21:1079–1101. 1929.
12. ROBERTSON, JOSEPH H. Effect of frequent clipping on the development of certain grass seedlings. Plant Physiol., 8:425–447. 1933.
13. SAMPSON, A. W., and MALMSTEN, H. E. Grazing periods and forage production on the national forests. U. S. D. A. Bul. 1405. 1926.
14. SPRAGUE, HOWARD B. Root development of perennial grasses and its relation to soil conditions. Soil Science, 36:189–209. 1933.
15. STURKIE, D. G. The influence of various top-cutting treatments on rootstalks of Johnson grass (*Sorghum halepense*). Jour. Amer. Soc. Agron., 22:82–93. 1930.

A STUDY OF A CORRELATION OF CHEMICALLY AVAILABLE PHOSPHORUS WITH CROP YIELDS[1]

A. C. RICHER AND J. W. WHITE[2]

ONE of the most widely accepted chemical methods for the determination of available phosphorus is that proposed by Truog (8).[3] It has been shown by several workers (1, 2, 5, 6, 7) that the Truog method compared well with other methods, and in general, gave good agreement with field results. However, the method has not been applied to phosphate field plats, except for the work of Snider (7).

The purpose of this study, therefore, was to determine the degree of correlation of available phosphorus as determined by the Truog method with crop yields of two field plat fertilizer experiments. These include comparisons of plats receiving various carriers and amounts of phosphate fertilizers.

The first series of plats considered were those of one tier of a phosphate field plat experiment which compares the various sources of phosphorus, such as, superphosphate, rock phosphate, steamed bone meal, and basic slag. This experiment was begun in 1916 and the relative efficiency of the various sources as measured by crop yields was reported by Noll, Irvin, and Gardner in 1935 (4).

One tier of the Jordan soil fertility plats constituted the second series of plats considered. This experiment was planned to test comparative effects of fertilizers without any special reference to phosphorus. This soil fertility experiment, the oldest extensive field plat experiment in America, was laid out in 1881, and the results for 50 years were summarized in 1931 (3).

Both of these experiments are located at the Pennsylvania Agricultural Experiment Station. The soil is Hagerstown silt loam, a residual soil of limestone origin. The rotation is corn, oats, wheat, and hay (mixed clover and timothy) one year each. The fertilizers are applied to corn and wheat only.

EXPERIMENTAL

Samples were taken from tier 2 of the phosphate field experiment and from tier 4 of the Jordan soil fertility plats. The samples were taken with a soil auger to a depth of 7 inches. The soils were prepared for analysis by air drying and passing through a 20-mesh screen.

The available phosphorus was determined by the Truog method (8) which consists of extracting the soils with 0.002 N sulfuric acid, buffered at pH 3.0, and estimating the phosphorus in the extract colorimetrically.

The pH value was determined potentiometrically, the voltage reading being

[1]Authorized for publication on January 9, 1939 as paper No. 886 in the Journal. Contribution from the Department of Agronomy, Pennsylvania State College, State College, Pa. Series of the Pennsylvania Agricultural Experiment Station. Received for publication January 16, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 437.

taken immediately after the addition of quinhydrone to a 1 to 1 mixture of soil and distilled water.

All results are the average of at least two determinations.

DISCUSSION OF RESULTS

PHOSPHATE FERTILIZER PLATS

Since lime has been applied on all plats to meet the lime requirement, soil reaction is not a factor. However, the pH of the soil is indicated, but, as can be seen, the pH values do not vary much from pH 6.5.

For purposes of comparison, the plats pertaining to this study were grouped into Tables 1, 2, and 3. The total crop yields are expressed in pounds per acre and are the sum of the yields for one rotation preceding the time of sampling. The data presented in Tables 1 and 2 show that the crop yields correlate much better with the amounts of superphosphate added than with the available phosphorus of the soil. There is only a small increase in the available phosphorus with increasing amounts of superphosphate added (with one exception) whether the superphosphate is added with manure or commercial fertilizers. Although manure increased the crop yields considerably, there was a decrease of available phosphorus extracted

TABLE 1.—*Comparison of crop yields and available phosphorus on plats treated with rock phosphate and superphosphate when applied with uniform amounts of nitrogen and potash, phosphate experiment plats.**

Plat No.	Phosphate fertilizer	pH	Total crop yields per rotation in lbs. per 4 acres	Relative crop yield	Lbs. of available phosphorus per acre
10	None	6.68	8,668	100	22.4
3	150 superphosphate	6.88	12,166	140	27.2
4	300 superphosphate	6.66	13,378	154	21.6
7	450 superphosphate	6.69	15,296	176	28.8
9	600 superphosphate	6.74	15,282	176	46.4
14	150 rock phosphate	6.56	10,242	118	72.0
15	300 rock phosphate	6.47	11,097	128	152.0
17	450 rock phosphate	6.52	12,421	144	240.0

*Also 130 lbs. of nitrate of soda and 100 lbs. muriate of potash.

TABLE 2.—*Comparison of crop yields and available phosphorus of plats treated with rock phosphate and superphosphate when applied with 6 tons of manure, phosphate experiment plats.*

Plat No.	Phosphate fertilizer	pH	Total crop yields per rotation, lbs. per 4 acres	Relative crop yield	Lbs. of available phosphorus per acre
22	None	6.58	13,785	100	16.8
23	150 superphosphate	6.39	15,293	111	20.8
24	300 superphosphate	6.61	15,571	113	20.8
25	450 superphosphate	6.30	16,018	116	25.8
29	300 rock phosphate	6.52	15,834	115	176.0
30	450 rock phosphate	6.40	15,102	110	264.0
32	600 rock phosphate	6.29	16,980	123	316.0

(comparing Tables 1 and 2). It is apparent that the phosphorus of superphosphate, in excess of the amount taken up by the plants, is practically all fixed by the soil and is not dissolved by Truog's reagent.

The chemically available phosphorus was very high on the rock phosphate-treated plats. The increase in available phosphorus extracted was directly proportional to the amount of rock phosphate applied. The yields also increased with increasing amounts of rock phosphate,[4] but the increase was gradual and not proportional to the available phosphorus extracted. The addition of manure to rock phosphate increased the amount of available phosphorus extracted over the rock phosphate treatments alone. Although the available phosphorus as measured by the Truog method on the rock phosphate treatments was much greater than on the superphosphate treatments, the superphosphate was a much better source of phosphorus as evidenced by the higher crop yields produced.

This leads to the conclusion that all of the phosphorus extracted from the rock phosphate treatments is not available to the plants, although according to Truog's method it is termed readily available.

Table 3 compares the effects of various carriers of phosphorus when applied at the rate of 48 pounds of P_2O_5 per acre. The basic slag and superphosphate are highest and about equal in yield, with bone meal next, and rock phosphate as the poorest source of phosphorus. However, the chemically available phosphorus is greatest on the rock phosphate-treated plat. It is important to note also that the bone meal treatments behave like rock phosphate treatments but to a lesser degree, insofar as chemically available phosphorus is concerned.

TABLE 3.—*Comparison of crop yields and available phosphorus of plats treated with different carriers of phosphoric acid when applied with uniform amounts of nitrogen and potash, phosphate experiment plats.**

Plat No.	Phosphate fertilizer	pH	Total crop yields per rotation, lbs. per 4 acres	Relative crop yield	Lbs. of available phosphorus per acre
10	None	6.68	8,668	100	22.4
4	300 superphosphate†	6.66	13,378	154	21.6
12	200 bone meal†	6.43	11,888	129	43.2
13	300 basic slag†	6.71	13,306	154	28.0
14	150 rock phosphate†	6.56	10,242	118	72.0

*Also 130 lbs. of nitrate of soda and 100 lbs. muriate of potash.
†Each treatment = 48 lbs. P_2O_5 per acre.

Where either rock phosphate or bone meal has been applied Truog's extracting reagent dissolves considerable more phosphorus than is easily available to the plant. It was found that if rock phosphate was extracted alone or after being mixed with soil in amounts in which the rock phosphate is agriculturally applied, all of the rock phosphate was dissolved by Truog's reagent and therefore was termed readily

[4]The rock phosphate used until the spring application in 1928 was that which had been ground for making superphosphate. Thereafter, a more finely ground phosphate, intended for direct use, has been applied. There is no evidence that the more finely ground rock phosphate is more efficient (4).

available phosphorus. The phosphorus of rock phosphate is not as available to crops as that contained in superphosphate, as shown by Tables 1, 2, and 3. However, the chemically available phosphorus of the rock phosphate treatments is many times greater than on any other treatment. Snider (7) also noted the same behavior of rock phosphate-treated soils. It must be concluded therefore that rock phosphate when placed in neutral soils, such as in this experiment, is only slightly soluble in soil solution. The small amount that does dissolve is fixed either in a difficultly available form as basic ferric and aluminum phosphates, or in a moderately available form as the various calcium phosphates. A considerable portion of the rock phosphate, however, does not dissolve and remains as such in the soil, much the same as any inert material.

The extracting reagent, 0.002 N H_2SO_4 at pH 3, undoubtedly dissolves all phosphates combined with calcium, but it is apparent from the crop yields that all calcium phosphate compounds, such as in rock phosphate or bone meal, are not "readily available" to the plant.

The results indicate, therefore, that where rock phosphate has been applied, Truog's method is not applicable unless the investigator takes into consideration the fact that the results in terms of available phosphorus will be unusually high. Direct comparisons between rock phosphate treatments and treatments of other carriers of phosphorus will lead to erroneous conclusions concerning the available phosphorus of the soils in question.

The same precautions must be observed when considering chemically available phosphorus of bone meal treatments. The results in terms of available phosphorus, although too high, are not nearly as high as with rock phosphate treatments. More data is presented below on bone meal-treated plats.

JORDAN SOIL FERTILITY PLATS

The available phosphorus and yields of one tier of the Jordan soil fertility plats is shown in Table 4. It can be seen that, in general, there is an excellent correlation between the available phosphorus and the crop yields. The two bone meal plats, Nos. 12 and 35, are outstanding in that the same results are found as were noted with the rock phosphate treatments of the first series of plats discussed, namely, that the available phosphorus is considerably higher than is evidenced by crop yields. Apparently, bone meal contains phosphorus which is not readily available for plant use and yet is termed readily available by virtue of the fact that it is soluble in Truog's reagent.

The manure plats, Nos. 16, 18, and 20, on the other hand, gave yields which, as would be expected, were much higher than the available phosphorus would indicate.

In general, however, the correlation between yields and available phosphorus was remarkable. The coefficient of correlation on all 36 plats was .55. If the two bone meal plats, Nos. 12 and 35, were omitted from the calculation, the coefficient of correlation rose to .82. Then, if in addition to the two bone meal plats, the three manure plats,

Nos. 16, 18, and 20, were omitted from the calculation, the coefficient of correlation was .91.

TABLE 4.—*Comparison of crop yield and available phosphorus of tier 4 of the Jordan soil fertility plats.*

Plat No.	Treatment*	pH	Total crop yield per rotation, lbs. per 4 acres	Lbs. of available phosphorus per acre
1	No treatment	7.50	6,682	16.8
2	N, 24 lbs. N (D. B.)	6.91	7,169	18.4
3	P	6.98	10,287	41.6
4	K	6.98	6,549	14.4
5	NP, 24 lbs. N (D. B.)	6.56	11,811	38.4
6	NK, 24 lbs. N (D. B.)	6.91	7,470	18.4
7	PK	6.49	15,565	33.6
8	No treatment	7.01	7,447	17.6
9	NPK, 24 lbs. N (D. B.)	6.26	15,802	37.6
10	NPK, 48 lbs. N (D. B.)	6.05	15,815	34.4
11	NPK, 72 lbs. N (D. B.)	6.54	16,266	39.2
12	NPK, 30 lbs. N (D. B.)	7.35	13,382	98.0
13	Corn 6 tons manure + P, wheat NPK†	7.79	11,843	28.8
14	No treatment	7.89	5,980	17.6
15	PK unlimed	6.88	13.066	30.4
16	6 tons manure	7.27	16,502	19.2
17	NPK, 24 lbs. N (D. B.)	6.81	14,820	28.8
18	8 tons manure	7.15	17,126	24.0
19	NPK, 48 lbs. N (D. B.)	6.90	15,613	32.0
20	10 tons manure	7.07	18,761	24.0
21	NPK, 72 lbs. N. (D. B.)	6.61	16,883	32.0
22	6 tons manure + 30 P_2O_5	8.25	18,506	44.8
23	CaO up to 1922; no treatment since	8.38	9,335	26.4
24	No treatment	7.07	8,220	16.0
25	PK unlimed	5.47	14,453	40.8
26	NPK, 24 lbs. N ($NaNO_3$)	6.49	18,056	41.6
27	NPK, 48 lbs. N ($NaNO_3$)	6.46	17,977	38.4
28	NPK, 72 lbs. N ($NaNO_3$)	6.46	18,842	47.2
29	PK	6.44	17,322	46.4
30	NPK, 24 lbs. N $(NH_4)_2SO_4$	6.44	20,165	48.0
31	NPK, 48 lbs. N $(NH_4)_2SO_4$	6.61	22,761	58.0
32	NPK, 72 lbs. N $(NH_4)_2SO_4$	6.58	22,204	46.4
33	$CaSO_4$ up to 1922; no treatment since	7.12	9,765	20.0
34	$CaCO_4$ up to 1922; no treatment since	8.38	11,006	28.0
35	NPK, 30 lbs. N (D. B.)	6.78	18,447	60.0
36	No treatment	7.78	12,224	28.0

*D. B. = Dried blood; P = 48 lbs. P_2O_5 per acre in superphosphate; K = 100 lbs. K_2O per acre in muriate of potash.

On plats 12 and 35, P is derived from bone meal. No lime applied from 1881 to 1921, except on plats 22, 23, and 34. Lime was applied to all plats in 1922 and 1932, except plat 25. Dissolved bone black was the source of P, except on plats 12 and 35, up to 1917; since then superphosphate has been substituted for it. All treatments are applied to corn and wheat.

†To corn, 6 tons manure + 30 lbs. P_2O_5; to wheat, 10 lbs. N ($NaNO_3$) + 60 lbs. P_2O_5 + 50 lbs. K_2O.

The correlation is even more impressive when it is realized that the nitrogen and potash are not constants on all the plats. Nitrogen in particular is applied at three different rates and in three different forms.

Because of the high degree of correlation of yields with available phosphorus, it can be concluded that phosphorus is one of the primary limiting factors for crop growth on this particular soil. Phos-

phorus, however, is not the only limiting factor, since the application of phosphorus alone (plat 3) is not sufficient to obtain high crop yields.

The lack of correlation on the phosphate fertilizer plats was probably due to two reasons. First, various sources of phosphorus were applied and the readily available phosphorus as determined by the Truog method varied with the phosphorus carrier applied. Second, these plats were begun 35 years later than the Jordan soil fertility plats and so the older plats have had a much longer time to approach an equilibrium with respect to phosphorus applied and phosphorus available.

SUMMARY AND CONCLUSIONS

This study included a correlation of the readily available phosphorus as measured by the Truog method with crop yields of two field plat fertilizer experiments. The first was a phosphate fertilizer experiment and the second a general fertilizer experiment.

The results indicate that when readily available phosphorus as determined by the Truog method is to be used as one index of fertility, it is of the utmost importance to know the history of the soils in question, particularly as to the kind of phosphorus fertilizers that have been applied. The best comparative results on any particular soil will be obtained when the same carrier of phosphorus has been applied to all the soils studied. Erroneous conclusions will be drawn if various phosphorus fertilizers were used on the soils examined, unless the investigator takes into consideration the limitations of the method in the interpretation of the results.

As a result of these studies, the following conclusions seem justified:

1. There is no correlation of available phosphorus with crop yields in the comparison of plats receiving various carriers of phosphorus, such as superphosphate, rock phosphate, basic slag, and bone meal.

2. Plats receiving double or triple amounts of superphosphate showed only small increases in the available phosphorus extracted.

3. The available phosphorus of rock phosphate-treated plats was directly proportional to the amount applied, but it was many times higher than that of plats receiving superphosphate in equivalent amounts.

4. Truog's reagent dissolved considerably more phosphorus from soils treated with rock phosphate than is easily available to the plant as measured by crop yields. The same condition occurred with bone meal treatments but to a lesser degree.

5. The available phosphorus showed an excellent correlation with crop yields on one tier of the Jordan soil fertility plats. The only exceptions were the few plats receiving either bone meal or manure. If these plats were omitted in the calculation, the coefficient of correlation was .91. This high correlation is due to the fact that the phosphorus carrier was always the same, namely, superphosphate, and that these plats are approaching a phosphorus equilibrium after more than 50 years of existence.

LITERATURE CITED

1. ENGBERG, C. A., and SPURWAY, C. H. A comparison of field methods for determining the available phosphorus of soils. Jour. Amer. Soc. Agron., 25:354-360. 1933.
2. HOCKENSMITH, R. D., GARDNER, R., and GOODWIN, J. Comparison of methods for estimating available phosphorus in alkaline calcareous soils. Colo. Agr. Exp. Sta. Tech. Bul. 2. 1933.
3. NOLL, C. F., GARDNER, F. D., and IRVIN, C. J. Fiftieth anniversary of general fertilizer tests. Penn. Agr. Exp. Sta. Bul. 264. 1931.
4. ———, IRVIN, C. J., and GARDNER, F. D. Field experiments with phosphates. Penn. Agr. Exp. Sta. Bul. 315. 1935.
5. ROST, C. O., and PICKNEY, R. N. Colorimetric methods for the determination of readily available phosphorus. Jour. Amer. Soc. Agron., 24:377-395. 1932.
6. SMITH, F. B., BROWN, P. E., and SCHLOTS, F. E. A comparison of the Niklas and Truog methods for determining available phosphorus in soils. Jour. Amer. Soc. Agron., 24:452-460. 1932.
7. SNIDER, H. J. A comparison of methods for determining the available phosphorus in soils. Jour. Amer. Soc. Agron., 24:680-686. 1932.
8. TRUOG, E. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874-882. 1930.

POTASH AVAILABILITY STUDIES IN PENNSYLVANIA ORCHARD SOILS[1]

E. C. DUNKLE, F. G. MERKLE, AND R. D. ANTHONY[2]

DURING the season of 1937 Dunbar and Anthony (2)[3] noted what appeared to be definite cases of potash deficiency in certain peach orchards. This deficiency was manifested by the color and curling of the leaf and was apparently overcome quite rapidly by applying soluble potassium salts around affected trees. It seemed possible that, since many growers of both apples and peaches use little or no potash in their fertilizer, the lack of this element might be beginning to show deficiency symptoms and that other orchards showing no visible symptoms at present might be on the verge of a deficiency. With deep-rooted perennials like apples and peaches, a deficiency could exist without noticeably lowering the yield or wood growth and still gradually influence the vigor, longevity, and finally the yield.

It is realized that field comparisons with and without potash provide the best answer to the question and that such comparisons should be made over a considerable period of years to produce valid conclusions. Nevertheless, pending the initiation of such trials and to provide a better basis upon which to make field trials, the following soil studies were planned. These are in a sense preliminary and part of a more comprehensive program of study on the subject of soil potash availability.

The phases of study reported in this paper are as follows:

1. The relative amounts of exchangeable potassium in surface vs. subsoils in Pennsylvania orchards.
2. The relation between the amount of organic matter in orchard soils and exchangeable potassium.
3. A comparison between different soil series in regard to exchangeable potassium.
4. A comparison of rapid tests for exchangeable soil potassium with a routine procedure.
5. Foliage analysis as indicative of deficiency and response.

Forty-seven commercial orchards representing the major fruit sections of the state (Fig. 1) were examined and soil samples taken. Field notes included the type of soil, condition of tree, kind and amount of fertilizer, and lime and manure used, together with the cover cropping or other cultural system. Orchards were selected having high and low organic contents. Some received potash fertilizers, others none. In addition to samples taken in 1938 there were available the orchard soil samples taken by Shaulis and Merkle (9) in their study of the effects of orchard management practices upon the

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[1]Authorized for publication on January 14, 1939, as paper No. 888 in the Journal Series of the Pennsylvania Agricultural Experiment Station. Received for publication January 19, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 457.

organic content and porosity. Valuable advice in the choice of sites was received from C. O. Dunbar, N. J. Shaulis, John Reuf, and others.

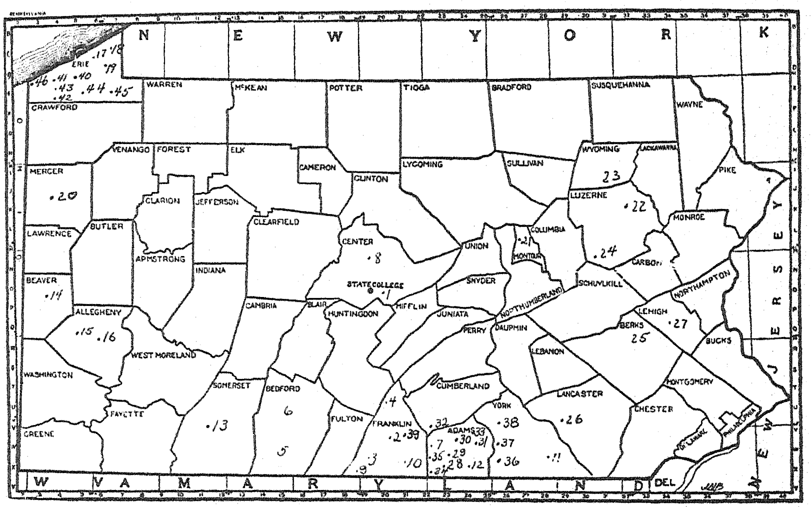

FIG. 1.—Distribution of sites.

RELATIVE AMOUNTS OF EXCHANGEABLE POTASSIUM IN SURFACE VS. SUBSOILS

Due to the greater clay content of the subsoils of practically all podzolic soils, more total potassium is found in the lower layers. However, organic matter in the surface soil may be expected to maintain a higher level of exchangeable potassium in the surface. This is partly the result of biological activity and partly physico-chemical. The surface soils, taken to the depth to which plowing was customary, were compared with the subsoils taken in a zone 12 inches below the plow depth. The exchangeable potassium was considered as most nearly representing that which is available to plants during a growing season. It was determined by extracting the soil with N/4 sodium acetate made up at pH 5.0 and determining the potassium in the extract by the cobalti-nitrite volumetric method.

The data taken from Table 1 are shown graphically in Fig. 2. Of the 72 cases studied, 67 showed greater quantities of exchangeable potassium in the surface soil. Five cases showed greater amounts in the subsoil, but these were, with one exception, within the limit of error for the determination. The mean difference between the surface soils and subsoils was 57 pounds and the odds against this difference being due to chance are greater than 10,000 to 1. Such evidence commands attention to the possible effects of erosion on the potash status of soils. Further studies contemplated will determine what properties and processes in the surface soil give rise to its higher exchangeable potassium content.

TABLE 1.—*Summary of sites and analyses.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Site 1, State College, Center County				
2226	Hagerstown silt loam	Surface	Alfalfa sod	2.04	155	250	1
2234	Hagerstown silt loam	Surface	Legume cover crop	1.50	176	250	2
			Site 2, Scotland, Franklin County				
2242	Hagerstown clay loam	Surface	Cultivated	1.07	107	250	3
2241	Hagerstown clay loam	Surface	Cultivated	1.01	113	200	4
			Site 3, Greencastle, Franklin County				
2238	Hagerstown silt loam	Surface	Sod 40 years	1.74	185	350	5
2247	Hagerstown silt loam	Subsoil		0.30	158	300	7
2237	Hagerstown silt loam	Surface	Sod 15 years	1.53	91	200	6
			Site 4, Waynesboro, Franklin County				
2243	Murrill loam	Surface	Sod	1.67	189	300	8
2248	Murrill loam	Subsoil		0.46	86	50	10
2245	Murrill loam	Surface	Cultivated	0.70	53	50	9
			Site 5, Mann's Choice, Bedford County				
2265	Gilpin shaley silt loam	Surface	Sod	1.72	93	200	11
2266	Gilpin shaley silt loam	Subsoil		0.79	38	50	14
2261	Gilpin shaley silt loam	Surface	Cultivated	1.48	80	150	12
2262	Gilpin shaley silt loam	Surface	Cultivated	1.42	85	200	13

			Site 6, New Paris, Bedford County				
2259	Gilpin silt loam	Surface	Sod	2.84	82	200	15
2260	Gilpin silt loam	Subsoil		1.92	109	150	20
2253	Gilpin silt loam	Surface	Cultivated	1.12	80	100	16
2254	Gilpin silt loam	Subsoil		0.50	32	50	19
2252	Gilpin shaley silt loam	Surface	Cultivated	1.44	53	150	17
2258	Gilpin shaley silt loam	Surface	Cultivated	2.41	130	200	18
			Site 7, McKnightstown, Adams County				
2274	Penn silt loam	Surface	Sod	1.95	199	300	21
2275	Penn silt loam	Subsoil		0.24	70	50	26
2273	Penn silt loam	Surface	Sod	1.84	205	300	22
2276	Penn silt loam	Surface	Sod	1.60	198	300	23
2269	Penn silt loam	Surface	Cultivated	1.76	183	200	24
2270	Penn silt loam	Surface	Cultivated	1.49	201	350	25
			Site 8, Pleasant Gap, Center County				
2285	Dekalb loam	Surface	Sod	2.10	92	200	27
2284	Dekalb loam	Subsoil		0.65	55	150	29
2281	Dekalb loam	Surface	Young sod	1.23	71	100	30
2279	Dekalb loam	Subsoil		0.33	40	50	28
			Site 9, Zullinger, Franklin County				
2291	Hagerstown loam	Surface	Sod	1.69	188	300	31
2293	Hagerstown loam	Subsoil		0.29	61	100	32
			Site 10, Waynesboro, Franklin County				
2309	Edgemont loam	Surface	Cultivated	1.10	91	200	33
2310	Edgemont loam	Subsoil		0.19	81	200	35
2311	Edgemont loam	Surface	Cover cropped	1.19	75	150	34
2312	Edgemont loam	Subsoil		0.26	45	100	37
2307	Edgemont loam	Subsoil	Woods	0.64	142	300	36
			Site 11, York, York County				
2302	Conestoga silt loam	Surface	Sod	2.11	127	250	38
2297	Conestoga silt loam	Subsoil		0.61	75	250	41
2300	Conestoga silt loam	Surface	Cultivated	0.96	80	250	39
2301	Conestoga silt loam	Surface	Cover cropped	1.70	81	250	40

TABLE 1—*Continued.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Site 12, Arendtsville, Adams County				
2314	Penn loam	Surface	Sod	1.33	51	100	42
2292	Penn loam	Surface	Cultivated	0.59	65	150	43
2306	Penn loam	Surface	Cultivated	0.70	49	150	44
2305	Penn loam	Surface	Cultivated; later alfalfa	0.81	100	200	45
2305	Penn loam	Subsoil	Woods	0.64	88	200	46
			Site 13, Somerset, Somerset County				
2318	Dekalb sandy loam	Surface	Sod	3.57	203	300	47
2320	Dekalb sandy loam	Surface	Cultivated	1.69	100	100	48
2315	Dekalb silt loam	Surface	Cultivated	1.72	152	250	49
2317	Dekalb silt loam	Subsoil	Woods	0.38	51	50	50
			Site 14, Mars, Allegheny County				
2323	Westmoreland loam	Surface	Sod	1.92	110	250	51
2326	Westmoreland loam	Subsoil		0.27	44	100	55
2322A	Westmoreland loam	Surface	Cultivated	1.19	81	200	52
2324	Westmoreland loam	Subsoil		0.32	44	50	54
2322B	Westmoreland loam	Surface	Cultivated	1.08	83	100	53
			Site 15, Wexford, Allegheny County				
2342	Westmoreland loam	Surface	Sod	1.75	181	300	56
2341A	Westmoreland loam	Surface	Cultivated	1.03	89	100	57
2341B	Westmoreland loam	Subsoil		0.32	44	100	58

			Site 16, Baden, Beaver County				
2329	Gilpin loam	Surface	Sod	1.78	95	150	59
2328	Gilpin loam	Subsoil		0.54	48	100	61
2327	Gilpin loam	Surface	Young sod	2.10	76	100	60
			Site 17, North East, Erie County				
2332	Dunkirk sandy loam	Surface	Cultivated	1.57	105	150	62
2339A	Dunkirk sandy loam	Subsoil		0.30	18	50	66
2333	Dunkirk sandy loam	Surface	Cultivated	1.91	174	200	63
2339B	Dunkirk sandy loam	Subsoil	Cover cropped	0.57	56	100	67
2334A	Dunkirk sandy loam	Surface	Cover cropped	1.49	101	200	64
2334B	Dunkirk sandy loam	Surface	Cover cropped	1.34	72	100	65
			Site 18, North East, Erie County				
2344	Dunkirk sandy loam	Surface	Sod	2.19	138	250	68
2343	Dunkirk sandy loam	Surface	Sod	1.85	268	300	69
2338	Dunkirk sandy loam	Surface	Cultivated	1.17	97	200	70
			Site 19, North East, Erie County				
2345	Dunkirk sandy loam	Surface	Cultivated	2.06	50	50	71
2349	Dunkirk sandy loam	Surface	Cover cropped	1.46	67	200	72
2346	Dunkirk sandy loam	Subsoil		0.58	29	100	73
			Site 20, Mercer, Mercer County				
2351	Volusia silt loam	Surface	Sod	2.73	109	300	74
2354	Volusia silt loam	Surface	Cover cropped	1.45	153	200	75
2355	Volusia silt loam	Subsoil		1.58	168	250	76
			Site 21, Danville, Montour County				
2357	Dekalb sandy loam	Surface	Sod	1.10	44	50	77
2362	Dekalb sandy loam	Surface	Cultivated	0.79	54	50	78
2363	Dekalb sandy loam	Subsoil		0.34	59	50	79
			Site 22, Dallis, Luzerne County				
2364	Volusia silt loam	Surface	Sod	3.04	39	50	80
2365	Volusia silt loam	Surface	Cultivated	1.48	38	50	81
2366	Volusia silt loam	Surface	Young sod	1.74	43	50	82
2367	Volusia silt loam	Subsoil	Woods	0.61	36	50	83

TABLE 1.—*Continued.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000 Long method	Rapid method	Key No.
			Site 23, Falls, Wyoming County				
2376	Volusia silt loam	Surface	Sod	2.05	26	50	84
2377	Volusia silt loam	Surface	Cultivated	1.57	37	50	85
2374	Volusia silt loam	Surface	Cultivated	1.51	54	50	86
2375	Volusia silt loam	Subsoil		0.44	22	50	87
			Site 24, Wapwollopen, Luzerne County				
2378	Volusia silt loam	Surface	Sod	2.23	52	50	88
2383	Volusia silt loam	Surface	Sod	2.44	17	150	89
2381	Volusia silt loam	Subsoil	Woods	0.57	65	50	90
			Site 25, Hamburg, Berks County				
2401	Berks shaly loam	Surface	Sod	1.97	224	300	91
2386	Berks shaly loam	Surface	Cultivated	0.81	97	100	92
2384	Berks shaly loam	Subsoil		0.13	46	50	93
			Site 26, Ephrata, Lancaster County				
2406	Hagerstown silt loam	Surface	Sod	1.98	110	100	94
2407	Hagerstown silt loam	Subsoil		—	36	50	—
2402	Hagerstown silt loam	Surface	Young sod	2.15	151	400	95
2405	Hagerstown silt loam	Surface	Sod	1.12	98	250	96
			Site 27, Allentown, Lehigh County				
4661	Berks shaly loam	Surface	Complete fertilizer cultivated	2.07	335	350	97
4662	Berks shaly loam	Subsoil		1.25	152	200	98
4663	Berks shaly loam	Surface	Complete fertilizer sod	4.15	493	350	99
4664	Berks shaly loam	Subsoil		2.23	374	300	100

			Site 28, Biglerville, Adams County				
4665	Ashe loam	Surface	Nitrogen only, sod	1.65	94	150	101
4666	Ashe loam	Subsoil		0.50	102	150	102
4667	Ashe loam	Surface	Nitrogen only, cultivated	1.79	70	100	103
4668	Ashe loam	Subsoil		0.62	74	150	104
4669	Ashe loam	Surface	Nitrogen only, cultivated	1.15	53	100	105
4670	Ashe loam	Subsoil		0.47	46	150	106
4671	Ashe loam	Surface	Manure, cultivated	1.32	136	150	107
4672	Ashe loam	Subsoil		0.46	52	150	108
			Site 29, Arentsville, Adams County				
4673	Penn loam	Surface	Complete fertilizer cover cropped	1.49	182	350	109
4674	Penn loam	Subsoil		0.40	136	250	110
4675	Penn loam	Surface	Complete fertilizer cover cropped	1.84	336	350	111
4676	Penn loam	Subsoil		0.52	220	300	112
4677	Penn loam	Surface	Complete fertilizer cover cropped	1.07	93	150	113
4678	Penn loam	Subsoil		0.35	57	250	114
4750	Penn loam	Surface	Complete fertilizer cover cropped	1.65	285	300	150
4751	Penn loam	Subsoil		0.38	190	200	151
4752	Penn loam	Surface	Complete fertilizer cover cropped plus additional potash	1.72	214	250	152
4753	Penn loam	Subsoil		0.36	89	100	153
4754	Penn loam	Surface	Complete fertilizer cover cropped	1.84	172	250	154
4755	Penn loam	Subsoil		0.65	100	100	155
			Site 30, Arendtsville, Adams County				
4679	Penn loam	Surface	No fertilizer, sod	1.31	113	200	115
4680	Penn loam	Subsoil		0.26	14	50	116
			Site 31, Arendtsville, Adams County				
4681	Porters silt loam	Surface	Manure, cover cropped	1.39	112	150	117
4682	Porters silt loam	Subsoil		0.25	19	50	118
			Site 32, Gardners, Adams County				
4683	Chester silt loam	Surface	Nitrogen only, cover cropped	1.53	175	250	119
4684	Chester silt loam	Subsoil		0.25	87	200	120
4685	Porters silt loam	Surface	Nitrogen only, cover cropped	1.72	85	100	121
4686	Porters silt loam	Subsoil		0.30	36	50	122
			Site 33, Biglerville, Adams County				
4688	Penn sandy loam	Surface	Manure, cultivated	1.41	233	200	123
4689	Penn sandy loam	Subsoil		0.35	72	50	124
4690	Penn sandy loam	Surface	Manure, sod	1.77	303	200	125
4691	Penn sandy loam	Subsoil		0.52	83	100	126

TABLE 1.—*Continued.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Site 34, Fairfield, Adams County				
4692	Porters silt loam	Surface	Intermediate potash, treatment	2.21	180	200	127
4693	Porters silt loam	Subsoil		1.09	36	50	128
			Site 35, Adams County				
4694	Porters silt loam	Surface	Nitrogen only, sod	1.70	145	50	129
4695	Porters silt loam	Subsoil		0.41	41	50	130
4756	Porters silt loam	Surface	No treatment, cover cropped	1.36	55	50	156
4757	Porters silt loam	Subsoil		0.43	11	50	157
4758	Porters silt loam	Surface	Manure, cover cropped	1.19	575	250	158
4759	Porters silt loam	Surface	Sawdust, cover cropped	1.47	53	50	159
4760	Porters silt loam	Surface	No treatment, cover cropped	1.48	46	50	160
4761	Porters silt loam	Subsoil		0.47	17	50	161
			Site 36, Stewartstown, York County				
4696	Manor loam	Surface	Nitrogen only, cover cropped	1.64	85	50	131
4697	Manor loam	Subsoil		0.15	23	50	132
4698	Manor loam	Surface	Complete fertilizer, cover cropped	1.41	96	50	133
4699	Manor loam	Surface	Complete fertilizer, cover cropped	1.21	87	50	134
4700	Manor loam	Subsoil		0.25	32	50	135
4742	Manor loam	Surface	Cultivated field, no fertilizer	1.41	55	50	142
4743	Manor loam	Subsoil		0.26	48	50	143
4744	Manor loam	Surface	Reforested area	1.66	127	150	144
4745	Manor loam	Subsoil		0.36	40	50	145
4746	Manor loam	Surface	Reforested area	1.15	48	50	146
4747	Manor loam	Subsoil		0.24	17	50	147
4748	Manor loam	Surface	Complete fertilizer	1.72	47	50	148
4749	Manor loam	Subsoil	General rotation	0.49	32	50	149

			Site 37, Stewartstown, York County				
4701	Manor loam	Surface	Straw mulch	1.33	140	150	136
4702	Manor loam	Subsoil		0.23	33	50	137
			Site 38, Loganville, York County				
4738	Chester silt loam	Surface	No treatment, sod	1.52	121	100	138
4739	Chester silt loam	Subsoil		0.33	91	50	139
4740	Chester silt loam	Surface	No treatment, cultivated	1.62	103	50	140
4741	Chester silt loam	Subsoil		0.38	63	50	141
			Site 39, Franklin County				
4762	Duffield silt loam	Surface	No treatment cultivated	1.09	79	50	162
4763	Duffield silt loam	Subsoil		0.29	52	50	163
			Unit 40, Girard, Erie County				
4716	Dunkirk loam	Surface	Complete fertilizer, cover cropped	1.35	68	50	164
4717	Dunkirk loam	Subsoil		1.13	57	100	165
			Unit 41, Girard, Erie County				
4718	Dunkirk sandy loam	Surface	Complete fertilizer, cultivated	1.38	75	100	166
4719	Dunkirk sandy loam	Subsoil		0.44	51	50	167
4720	Clyde silt loam	Surface	No fertilizer, cover cropped	3.28	58	50	168
4721	Clyde silt loam	Subsoil		0.61	51	50	169
			Unit 42, Girard, Erie County				
4722	Dunkirk gravelly loam	Surface	Complete fertilizer, cover cropped	1.49	100	150	170
4723	Dunkirk gravelly loam	Subsoil		0.63	55	50	171
4724	Dunkirk gravelly loam	Surface	Complete fertilizer, cover cropped	1.46	150	250	172
4725	Dunkirk gravelly loam	Subsoil		0.29	30	50	173

TABLE 1.—*Concluded.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Unit 43, Girard, Erie County				
4726	Dunkirk sandy loam	Surface	Complete fertilizer	0.67	54	150	174
4727	Dunkirk sandy loam	Subsoil	Cover cropped	0.25	20	50	175
			Unit 44, Girard, Erie County				
4728	Dunkirk gravelly loam	Surface	Newly cultivated ground	1.65	97	150	176
4729	Dunkirk gravelly loam	Subsoil		0.88	38	50	177
4730	Dunkirk gravelly loam	Surface	Newly cultivated ground	2.33	211	350	178
4731	Dunkirk gravelly loam	Subsoil		0.68	230	350	179
			Unit 45, Girard, Erie County				
4732	Dunkirk gravelly loam	Surface	No fertilizer	1.42	105	200	180
4733	Dunkirk gravelly loam	Subsoil	Cultivated	0.63	16	50	181
			Unit 46, East Springfield, Erie County				
4734	Dunkirk sandy loam	Surface	No fertilizer	1.27	18	50	182
4735	Dunkirk sandy loam	Subsoil	Cultivated	0.36	7	50	183
			Site 47, North Girard, Erie County				
4736	Dunkirk sandy loam	Surface	Intermediate K application	1.68	69	200	184
4747	Dunkirk sandy loam	Subsoil		0.49	20	50	185

RELATION BETWEEN AMOUNT OF ORGANIC MATTER IN ORCHARD SOILS AND EXCHANGEABLE POTASSIUM

Since it was shown conclusively that surface soils contain more replaceable potassium than subsoils and since it is well known that as erosion of surface soil gradually increases more and more subsoil is mixed into the surface by plowing, it seemed well to compare the organic content with exchangeable potassium.

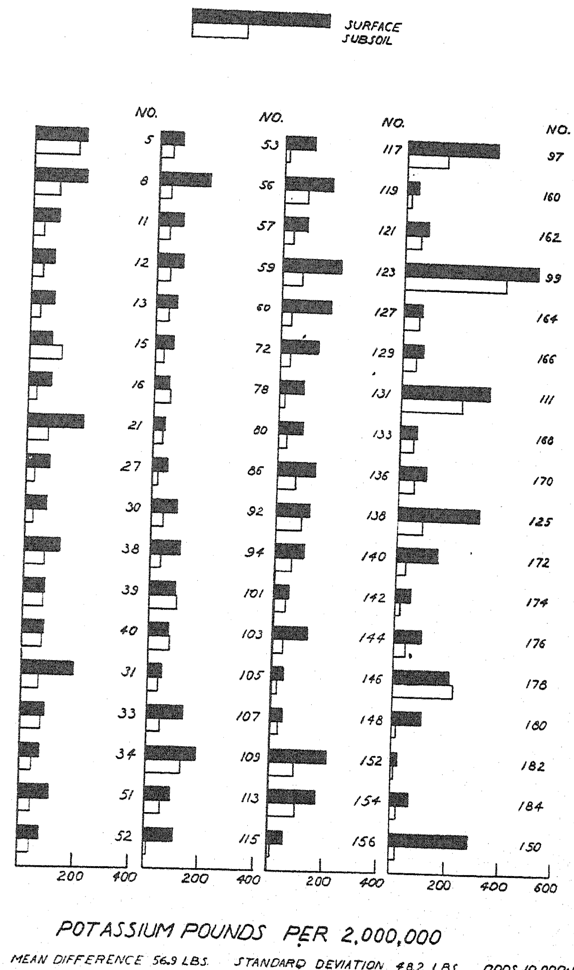

FIG. 2.—Replaceable potassium; surface vs. subsoil.

The organic content was determined by the chromic acid titration procedure of Schollenberger (4) as modified by Tuirin (7). The exchangeable potassium was determined as outlined above. Certain of the data from Table 1 are shown graphically as Fig. 3. In spite of the fact that several differences occur, such as difference in soil type, in

cover cropping, and in fertilizing and manuring, the correlation is reasonably good, the coefficient of correlation being $.501 \pm .03$.

In order to decrease the error due to grouping in one correlation distribution soils of several series, additional graphs were prepared showing the relationships between organic content and exchangeable potassium within soil families or related series. Within a given series or family the correlation in most cases is closer than where all series are grouped on a single distribution. These correlations were as follows: Dunkirk soils, $.49 \pm .07$; Penn and Berks soils, $.83 \pm .05$; Dekalb and Gilpin soils, $.61 \pm .07$; and Chester Manor and Porters soils, $.68 \pm .07$.

These findings are in agreement with a study made in 1934 and 1935 on soils of the rim experiments conducted by the Pomology division. In this experiment varying amounts of green rye are added to the surface of the soil in rims growing trees. It was found that as the amount of green rye added increased, the amount of replaceable potassium increased (Table 2.)

TABLE 2.—*Replaceable potassium in pounds per acre in surface and subsoil as influenced by varying amounts of rye added as green manure.*

N used	Soil layer	Green rye added*		
		0	3	6
I†	Surface	350	350	400
	Subsoil	170	180	180
II	Surface	200	300	300
	Subsoil	150	170	300
III	Surface	200	250	350
	Subsoil	230	250	250

*Figures denote relative amounts green material added.
†Numerals denote increasing amounts of nitrogen used.

In every case it can be noted that the larger additions of green rye increased the amount of replaceable potassium, attributable either to potassium contained in the organic matter added or to release from the soil, or both.

COMPARISON BETWEEN DIFFERENT SOIL SERIES IN REGARD TO REPLACEABLE POTASSIUM

When similar soil series are plotted with reference to organic content and replaceable potassium, a better correlation is generally obtained than when all series are grouped together, as in Fig. 3. This suggests that the mineralogical parentage of a soil is a factor to be considered. Accordingly, the average replaceable potassium content for all surface and subsoil samples of each series was determined and presented in Table 3.

The Penn and Hagerstown series contain relatively large amounts of replaceable potassium in both surface and subsoil, indicating that the nature of the parent material has a dominant influence since there

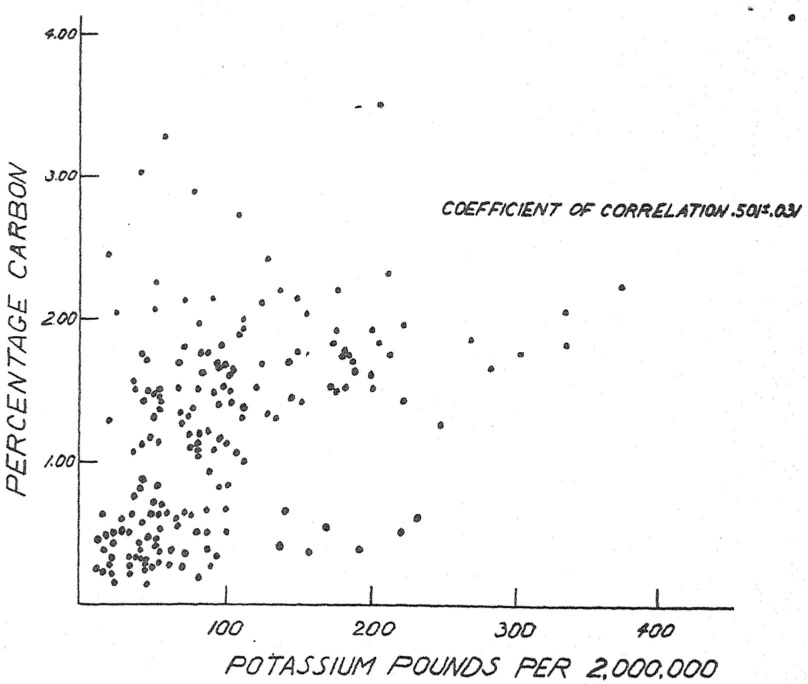

FIG. 3.—Exchangeable potassium vs. organic matter in 185 Pennsylvania orchard soils.

TABLE 3.—*The average amounts of exchangeable potassium in certain Pennsylvania soils.*

No.	Soil series	Lbs./2,000,000 average potassium		No. of samples
		Surface	Subsoil	
1	Penn	176	102	29
2	Hagerstown	130	82	12
3	Dunkirk	114	59	32
4	Dekalb	102	51	10
5	Gilpin	86	57	13
6	Volusia	57	73	14
7	Porters	97	27	13
8	Manor-Chester association	86	32	15

were poorly fertilized orchards within this group as well as in other soil series. The Chester-Manor association, the Porters, and the Volusia appear to be definitely lower in replaceable potassium in both surface and subsoil. The Dekalb, Gilpin, and Dunkirk are intermediate in this respect. A further investigation into the nature of the colloidal matter in some of the high and low potassium series is under way.

It is of interest to note that two soils showing the lowest average replaceable potassium, namely, the Chester-Manor association and the Porters, are the soils upon which Anthony and Dunbar (2) first located potassium deficiency symptoms in peach trees. It should be emphasized, however, that certain soil characteristics, such as the porosity and depth of root penetration, should be considered in interpreting the analysis. Doubtless higher potassium levels are needed in those soils which have dense subsoils.

COMPARISON OF RAPID TESTS FOR REPLACEABLE SOIL POTASSIUM WITH QUANTITATIVE PROCEDURES

If deficiencies of potassium are of frequent occurrence, there will be a real need for soil tests performed on short notice. Since rapid tests are now available and since their applicability has been questioned by some, it was decided to determine just how accurate they are when compared with the longer quantitative methods. Accordingly, the sodium acetate extracts obtained from all samples were tested by the rapid method essentially as outlined by Bray (1), except that the turbidity of the potassium cobalt nitrite precipitate was determined by comparing it with standards of known concentration rather than by the use of improvised comparators. Another portion of the same extract was analyzed accurately by the cobaltinitrite volumetric procedure now in common use (3). Fig. 4 shows the correlation between the rapid and the quantitative procedures.

It is clear from the distribution that the rapid procedure in general gives values higher than the quantitative procedure and that it would not be sufficiently accurate for precise experimental work. However, there is a reasonably good correlation between the two procedures, as shown by the coefficient of correlation, $\pm.78\pm.02$, and since no one at present can tell what is the threshold concentration for potassium in the soil, it is clear that the rapid method may be used with safety for rough diagnostic purposes. By the use of the rapid or quantitative procedure one can pick soils in which potassium deficiency is likely to occur, but he cannot say positively that it will occur on such soil.

FOLIAGE ANALYSIS AS INDICATIVE OF POTASSIUM DEFICIENCY AND RESPONSE

In order to determine whether or not there was any relationship between the potassium content of the leaf, expressed as percentage or as milligrams of potassium per leaf, and the deficiency symptoms or the amount of replaceable potassium in the soil, leaf samples were taken from representative trees from every orchard where soil samples were taken.

In all cases leaves were taken from the mid-portions of the current years growth. They were dried, ashed, and analyzed for potassium. It was realized at the outset that the leaf samples were taken too late in the season, at about the middle of August, and insufficient fertilizer combinations were available to apply the foliage diagnosis principles as set forth by Thomas (6). Nevertheless, we sought to gain some information, crude as it might be.

There was no connection between the potassium content of the leaf expressed as percentage of potassium or milligrams of potassium per leaf and the amount of replaceable potassium in the soil (Tables 4 and 5). This might be expected since the percentage of any element present in tissue is expressed upon the total growth which in itself depends upon all growth factors, nutritional and otherwise. In several cases the application of potassium in manure or inorganic

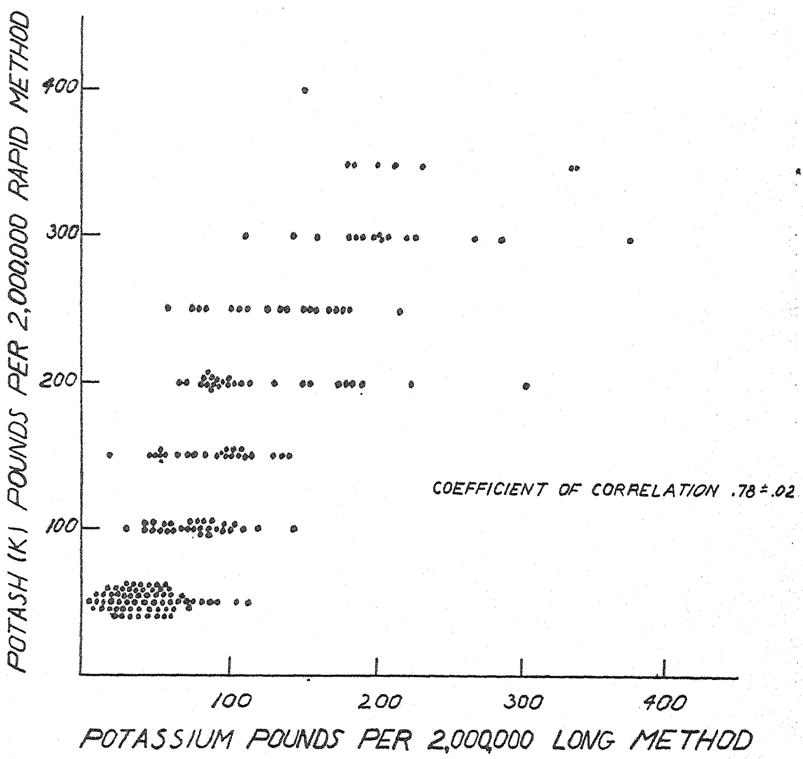

FIG. 4.—Rapid vs. long method for potassium.

salts showed no change in the potassium status of the soil as measured by exchange analysis, but the effects of such applications were apparent in the analysis of the leaves. Table 6 summarizes the data from two orchards not far apart on the Chester-Manor soil, one owned by Russel Shaw, the other by Howard Anderson. Here one grower has quite definitely experienced a potassium deficiency and has achieved responses from application of potash while the other has had none of the symptoms. The latter has used a heavy straw mulch. In Table 6 cases 1, 2, and 3 are from the Shaw orchard and case 4 from the Anderson orchard.

Case 1, receiving no added potassium, and cases 2 and 3, receiving additions one year only in the form of fertilizer and manure, show no essential difference in the amounts of replaceable potassium in the

TABLE 4.—*Comparison of apple leaves and soil analyses under varied treatments.*

Soil series	Treatment	Variety	Leaf		K Lbs./2,000,000 surface soils, Long method	Lab. No.
			% K	Mgms K/leaf		
Ashe	Nitrogen only, sod	York Imperial	1.28	4.5	94	4665
Ashe	Nitrogen only, sod	York Imperial	1.17	3.7	70	4667
Ashe	Nitrogen only, cultivated	Stayman Winesap	1.67	6.7	53	4669
Ashe	Manure, cultivated	Rambo	1.81	10.1	136	4671
Berks	Complete fertilizer, sod	Early (unidentified)	1.33	7.7	494	4663
Chester	Nitrogen only, cover cropped	Early (unidentified)	1.51	5.6	175	4683
Chester	No treatment, sod	Early (unidentified)	1.23	3.5	121	4738
Clyde	No treatment, cover cropped	Early McIntosh	0.47	1.8	58	4720
Duffield	No treatment, cultivated	Grimes Golden	1.40	4.2	79	4762
Manor	Nitrogen only, cover cropped	Rambo	0.74	3.7	85	4796
Manor	Complete fertilizer, cover cropped	Rambo	0.42	1.6	96	4798
Penn	Complete fertilizer, cover cropped	Jonathan	1.19	3.8	182	4673
Penn	Complete fertilizer, cover cropped	Jonathan	1.26	4.3	336	4675
Penn	Complete fertilizer, cover cropped	Wealthy	0.95	3.4	93	4677
Penn	No fertilizer, sod	York Imperial	1.06	3.4	113	4679
Penn	Manure, sod	Unidentified	1.12	4.2	303	4690
Penn	Complete fertilizer, cover cropped plus additional potassium	Grimes Golden	0.99	4.1	285	4750
Penn	Complete fertilizer, cover cropped plus additional potassium	Jonathan	0.67	1.8	214	4752
Porters	Manure, cover cropped	Unidentified	0.97	3.6	112	4681
Porters	Nitrogen only, cover cropped	Unidentified	1.04	4.3	85	4685
Porters	Intermediate potash treatment	Dutchess	0.89	4.6	180	4692
Porters	Nitrogen only, sod	Jonathan	0.78	2.9	145	4694

Coefficient of correlation between percentage of potassium in the leaf and exchangeable potassium in the soil was $.29 \pm .12$.

TABLE 5.—*Comparison of peach leaves and soil analyses under varied treatments.*

Soil series	Treatment	Variety	Leaf		K Lbs./2,000,000 surface soils Long method	Lab. No.
			% K	Mgms K/leaf		
Berks	Complete fertilizer, cultivated	Unidentified	1.70	5.2	335	4661
Dunkirk	Complete fertilizer, cover cropped	Rochester	0.93	2.9	68	4716
Dunkirk	Complete fertilizer, cultivated	South Haven	1.13	4.7	75	4718
Dunkirk	Complete fertilizer, cover cropped	Rochester	1.89	5.8	100	4722
Dunkirk	Complete fertilizer, cover cropped	Elberta	1.56	5.4	150	4724
Dunkirk	Complete fertilizer, cover cropped	South Haven	1.52	7.1	54	4726
Dunkirk	Newly cultivated ground	Rochester	2.42	9.1	97	4728
Dunkirk	Newly cultivated ground	Rochester	2.46	10.6	211	4730
Dunkirk	No fertilizer, cultivated	Rochester	0.60	1.7	105	4732
Dunkirk	No fertilizer, cultivated	Rochester	0.56	1.4	18	4734
Dunkirk	Intermediate K application	Rochester	1.20	4.4	69	4736
Manor	Nitrogen only, cover cropped	Elberta	0.71	1.6	85	4696
Manor	Complete fertilizer, cover cropped	Elberta	1.07	3.4	96	4698
Manor	Complete fertilizer, cover cropped	Unidentified	1.35	5.9	87	4699
Manor	Straw mulch	Unidentified	1.81	5.8	140	4701
Penn	Manure cultivated	Unidentified	2.16	6.5	223	4688
Porters	No treatment, cover cropped	Unidentified	1.34	4.9	55	4756
Porters	Manure, cover cropped	Unidentified	1.56	6.7	575	4758

Coefficient of correlation between percentage of potassium in the leaf and exchangeable potassium in the soil was .35±.12.

TABLE 6.—*Effects of soil treatment on Elberta peach leaf analyses and upon the replaceable potassium in the soil.*

Case No.*	Carbon, %	K in leaf, %	Mgms K in leaf	Lbs. K in surface soil	Lbs. K in subsoil
1	1.64	0.71	1.64	85	23
2	1.41	1.10	3.43	96	—
3	1.21	1.35	5.94	87	32
4	1.33	1.81	5.84	140	33

*Treatments:

1—4 lbs. $NaNO_3$ annually per tree.

2—4 lbs. $NaNO_3$ annually per tree; 1938 manure; 1937–38 500 lbs. 4–8–10 per acre, 3 lbs. KNO_3 per tree.

3—4 lbs. $NaNO_3$ annually per tree; 1938 manure; 1937–38 500 lbs. 4–8–10, 2,000 lbs. 4–8–7 in 1920's.

4—Straw mulch and nitrogen for last 5 years.

soil. The amount so added is not large enough to make a significant difference in the replaceable potassium of the soil when consideration is given to that lost through leaching and that removed by the trees and cover crop and the possibility of some being fixed in non-replaceable form. However, the compositon of the leaf readily reveals added potassium both in percentage and in total milligrams per leaf, the percentage in the leaf having increased from 0.71 to 1.35 and the total milligrams of potassium per leaf from 1.64 to 5.94. This is in agreement with numerous observations which we have made, namely, that a single application of potash salt or manure sufficient to influence the plant does not make a measurable difference in the amount of replaceable potassium in the soil. This must not be considered as demonstrating that testing is valueless. On the contrary it may indicate those levels of replaceable potassium in the soil which, when all other soil factors are properly evaluated, indicate the need of attending to the potash question.

In case 4, heavy mulching with straw with no applied potassium has resulted in no symptoms of deficiency in the leaf either by appearance or composition, and an increased quantity of exchangeable soil potassium. Wander and Gourley (8) have likewise found the straw mulch to enhance the available potassium content of the soil.

A case contrary to the one just described is that of the Landis Fruit Farm on Dunkirk gravelly loam in Erie County. Here one block of trees was affected with some physiological disorder diagnosed as a possible potassium deficiency. Another block on a soil definitely higher in organic matter was found to show none of these symptoms. Their relative analyses are given in Table 7.

TABLE 7.—*Comparison between an area showing a physiological deficiency and an adjacent one not showing such deficiency on Dunkirk gravelly loam.*

Case	Lbs. K, surface	Lbs. K, subsoil	Carbon, %	K in leaf, %	Mgms K in leaf
No symptoms......	211	230	2.33	2.5	10.6
Symptoms present..	97	38	1.65	2.4	9.1

At first sight the great difference between the affected and unaffected areas in replaceable potassium would substantiate the idea of a

potassium deficiency. However, this is a very permeable soil and probably will tolerate a lower level of potassium than would a more compact soil. The leaf analyses do not suggest potassium deficiency, the differences being scarcely significant and both quite high in comparison with peach leaves in general. A field trial is greatly needed to help interpret this type of result.

Nearly all samples of the Penn series were rather high in replaceable potassium while the leaf analyses do not appear to be above the average some being quite low. The cause of this is a matter for speculation, but its consistancy may lead to the conclusion that a high soil level of potassium availability cannot be an absolute criterion of a possible sufficiency. Conditions restricting the root systems would in all probability be expected to require higher levels of available nutrients for the tree to continue normal growth. The Penn soil has a compact subsoil and a readily dispersed surface soil.

SUMMARY AND CONCLUSIONS

1. Soil samples and leaf samples were obtained from 47 commercial orchards from different districts of Pennsylvania.

2. Surface soils were definitely higher than subsoils in replaceable potassium and loss of top soil by erosion is a factor in increasing the need of applied potassium.

3. Certain soil series were found to contain more replaceable potassium than others. A few were notably low.

4. The amount of replaceable potassium is related to the organic matter content of the soil.

5. The rapid method for determining replaceable potassium compares favorably with the quantitative cobalti-nitrite method and is satisfactory for determining the general level of soil potassium.

6. Leaf analyses did not correlate with the replaceable soil potassium but in some cases gave indications of the effects of potash application which could not be detected by exchange analyses.

7. Field experiments in which potassium salts are added to certain trees and not to others should be started on as many soil series as practicable. These are needed because so-called deficiency symptoms may be of dubious reliability.

LITERATURE CITED

1. BRAY, R. H. A test for replaceable and water-soluble potassium in soils. Jour. Amer. Soc. Agron., 24:312–316. 1932.
2. DUNBAR, C. O., and ANTHONY, R. D. Two cases of potassium deficiency in peach orchards in south central Pennsylvania. Proc. Amer. Soc. Hort. Sci., 35:320–325. 1938.
3. MILNE, G. Cobaltinitrite method of estimating potassium in soil extracts. Jour. Agr. Sci., 19:541–552. 1929.
4. SCHOLLENBERGER, C. J. Determination of soil organic matter. Soil Science, 31:483–486. 1931.
5. SHAW, CHARLES F. The soils of Pennsylvania. Pa. State College Bul. 132. 1914.
6. THOMAS, WALTER. Foliar diagnosis: Principles and practice. Plant Phys., 12:571–599. 1937.

7. TUIRIN, J. W. A new modification of the volumetric method of determining soil organic matter by means of chromic acid. Pedology, 5-6:36. 1931. (Russian with English summary.)
8. WANDER, I. W., and GOURLEY, J. H. Available potassium in orchard soils as affected by a heavy straw mulch. Jour. Amer. Soc. Agron., 30:438-446. 1938.
9. SHAULIS, N. J., and MERKLE, F. G. Some effects of orchard soil management practices upon the soil. Pa. Agr. Exp. Sta. Bul. 373. 1939.

SOME ASPECTS OF THE PHYSIOLOGY AND NUTRITION OF TOBACCO[1]

W. W. Garner[2]

IN carrying out fairly extensive fertilizer experiments with tobacco over a period of years in cooperation with several of the states in which this crop is of commercial importance, it soon became apparent that results to be obtained by the old conventional methods of conducting field plat tests and recording the fertilizer effect merely in terms of final crop yields and values could not be expected to furnish a basis for determining the mode of action of the fertilizer. It seemed clear that there was urgent need of developing a physiological approach to the fertilizer problem which would make possible a reasonably clear analysis of the biochemical and biophysical conditions associated with application of fertilizer to the soil and the mode of action of the fertilizer elements on plant growth and development. Our attention was first directed sharply to this situation by some unexpected results obtained in what seemed to be a simple fertilizer experiment of the old type which was begun in 1912 on Durham sandy loam or closely related soil type at the Oxford, N. C., tobacco station. The experiment, which at that time was considered to be a "potash test", involved adding to the soil four different rates of potash derived, in duplicate series, from high grade sulfate and muriate. The basal fertilizer treatment supplied nitrogen in the form of dried blood and phosphoric acid derived from a dicalcic phosphate.

Contrary to expectations, the two forms of potash did not give the same results (Table 1). The sulfate produced lower yields, there was a tendency toward a breakdown of the leaf tissue which is now known as drought spot, and, more important, a typical chlorosis of the leaves developed which has come to be known popularly as "sand drown". After further investigation the chlorosis was found to be due to magnesium deficiency and the results of the study were published in 1923 (1).[3] So far as is known this is the first recorded instance of the occurrence of magnesium deficiency in a field crop with accompanying characteristic deficiency symptoms in the plant. Occurrence and symptoms of magnesium hunger in corn, cotton, and soybeans also were reported (2).

The results obtained make it clear that, properly speaking, in reality this experiment was not a potash test at all; it was merely a

[1]Contribution from the Division of Tobacco and Plant Nutrition, U. S. Dept. of Agriculture. Most of the experimental data presented herein were obtained in connection with field experiments conducted in cooperation with the North Carolina Department of Agriculture and Experiment Station at the Oxford Tobacco Station and with the Maryland Agricultural Experiment Station at the Upper Marlboro field station. Also presented at the annual meeting of the Society held in Washington, D. C., November 16, 1938. Received for publication January 20, 1939.

[2]Principal Physiologist. Acknowledgment is made of effective cooperation on the part of J. E. McMurtrey, Jr., C. W. Bacon, J. D. Bowling, Jr., D. E. Brown, E. G. Moss, and W. M. Lunn. Brief reference is also made to the work of R. A. Steinberg on the mineral nutrition of *Aspergillus niger*.

[3]Figures in parenthesis refer to "Literature Cited", p. 471.

comparative test of two potash salts. Instead of a single variable there were three, namely, potassic, chloride, and sulfate ions, and interpretation of results in terms of potassium alone is not possible. It was found that failure of magnesium deficiency symptoms to appear in the plats receiving muriate of potash was due to the indirect effect of the chloride ion in making available a portion of the small magnesium reserve in the soil. It was shown, also, that chlorides in the tissue of the leaf have a tendency to prevent drought spot injury in addition to stimulating growth (3).

TABLE 1.—*Results of "potash tests," Oxford, N. C., illustrating effects of the anions of sulfate and muriate of potash.**

Pounds of potash applied as		Average yield† of tobacco in lbs., 1917–24 with		Average value‡ of crop, 1917–24 with		Pounds of sulfur (SO_3) applied as potassium sulfate	Pounds of chlorine applied as potassium chloride
Sulfate	Muriate	Sulfate	Muriate	Sulfate	Muriate		
—	—	—	—	—	—	0	0
12	12	493	612	$122	$161	10	11
24	24	617	682	$162	$206	20	22
36	36	619	710	$169	$231	31	33
80	80	645	714	$155	$215	68	73

*Basal treatment 800 pounds 4-8-0; nitrogen from dried blood, phosphoric acid from dicalcic phosphate (precipitated bone).
†Average yield of check 426 lbs.
‡Average value of check $84.

Since this experiment conclusively proved that for this soil a product supplying only the three elements nitrogen, phosphorus, and potassium does not constitute a complete fertilizer, it seemed necessary to inquire into the basis on which this commonly accepted definition of the complete fertilizer for tobacco as well as for other crops rests. Ash analyses of standard types of tobacco of normal growth disclose that of the six macro elements long recognized as essential to the plant, the content of calcium is similar to that of potassium and the content of magnesium and sulfur is similar to that of phosphorus while the nitrogen content is intermediate. In other words, the crop requirements as to the two groups of elements are about the same (Table 2). Turning to the light sandy and sandy loam soils on which so much of the tobacco crop is grown, especially those of the Atlantic Coastal Plain, available analyses, though limited, indicate that in general the content of calcium, magnesium, and sulfur is likely to be no greater, and may be much less, than the content of nitrogen, phosphorus, and potassium (7, 9). (See Table 2.) This situation suggests that for normal crop production the soil's supply of the first-named group is quite as likely to be deficient as the supply of the last-named elements, except that observation indicates rainfall has a greater effect on evidence of deficiency of sulfur in the crop than of the other five elements.

Fairly extensive tests have confirmed this assumption in three ways, *viz.*, (a) when any one of the three elements in question is omitted from the fertilizer the crop frequently manifests characteristic

TABLE 2.—*Relative quantities of the several macro elements required by the tobacco crop and their relative content in typical light tobacco soils.*

Tobacco type	Pounds in normal crop of 1,000 pounds leaf and 500 pounds of stalks					
	N	P_2O_5	K_2O	CaO	MgO	SO_3
Flue-cured (cigarette)	37	9	45	45	10	10
Connecticut Valley (cigar)*	65	11	121	74	13	24
Soil type	**Percentage content of soil**					
Norfolk fine sandy loam (0–16 in.)	0.04	0.04	0.05	0.03	Trace	0.05
Tifton fine sandy loam (0–12 in.)	0.04	0.04	0.10	0.05	Trace	0.06
Portsmouth fine sandy loam (0–12 in.)	0.05	0.05	0.06	Trace	Trace	0.03
Durham sandy loam (0–10 in.)	—	0.12	3.96	0.89	0.19	0.06
Merrimac sandy loam	0.15	0.32	1.44	1.03	0.50	—

*The actual average yield of Connecticut Valley cigar binder leaf is about 1,500 pounds, with corresponding increase in mineral requirements.

deficiency symptoms similar to those obtained in solution cultures; (b) under such treatment the depression in growth is likely to be as great as when nitrogen, phosphorus, or potassium is omitted; and (c) ash analysis shows in the crop a much reduced content of the element omitted in the fertilizer (Table 3). Accordingly, it would seem that for these soils a complete fertilizer must contain all of the six elements under consideration and in quantities of the same order of magnitude. Of course in the past, with the use of complex fertilizer materials, this requirement has been largely complied with, though for the most part unintentionally. There appears to be no real basis for separating the six elements into groups of major and minor, or primary and secondary, elements; rather, all may well be placed on the same footing (Fig. 1). In our present tobacco fertilizer work consideration is given each of these elements from the standpoint of introducing into eact test as far as possible only a single variable with respect to the plant food supply (Table 3). This happens to be a matter of special importance in the case of tobacco since the relative supply of each of the six elements is capable of influencing the quality and commercial value of the crop.

Plant physiologists have long considered that plants may be cultured successfully in three-salt solutions if the salts supply nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur (and a trace of iron). In dealing with the soil as a culture medium, agronomists came to speak of a three-element fertilizer as being all-sufficient for crop growth though in practice the physiologist's three-salt mixture or its equivalent in complex organic materials was always used. Our experience with tobacco as well as the known chemical characteristics of the soil types under consideration would indicate that many of these soils are to be regarded as hardly more than somewhat impure sand culture media so that qualitatively at least their requirements as to a complete nutrient solution or salt mixture are fundamentally those applying to the pure sand cultures of the physiologist.

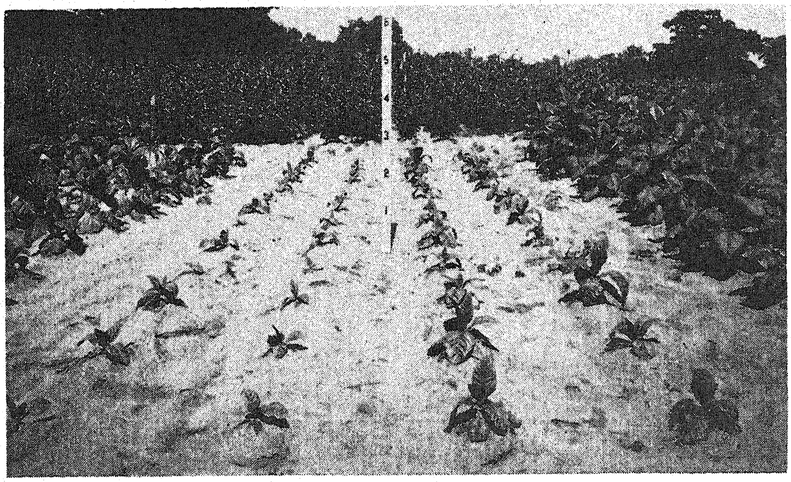

FIG. 1.—Tobacco in center plat received as fertilizer a mixture of nitrate of potash and ammonium phosphate. The plat to right received, in addition, calcium and magnesium. Photographed September 7.

TABLE 3.—*Growth of tobacco and absorption of macro elements as influenced by fertilization, Upper Marlboro, Maryland.*

Soil		Percentage composition					
		N	P_2O_5	K_2O	CaO	MgO	SO_3
Collington loamy sand		0.04	0.07	0.45	0.10	0.17	—
Fertilizer treatment	Total crop yield (leaf and stalk), lbs.	Quantity absorbed by the crop, lbs.					
Complete fertilizer*	907	17.6	5.3	32.8	24.4	5.1	2.6
Nitrogen omitted	405	*9.1*	3.3	18.6	7.2	2.9	—
Phosphorus omitted	166	5.6	*0.7*	6.7	3.2	1.2	0.6
Potassium omitted	404	11.0	2.5	*6.3*	8.5	2.9	—
Calcium omitted	349	12.5	1.7	11.4	*2.1*	2.8	—
Magnesium omitted	382	11.5	2.1	15.6	8.0	*1.1*	—
Complete fertilizer†	1,733	—	—	—	—	—	4.7
Sulfur omitted	1,350	—	—	—	—	—	3.1‡

N P_2O_5 K_2O CaO MgO SO_3 Cl B

*Complete fertilizer 1,000 lbs. of 6 — 6 — 6 — 8 — 2 — 2 — 2 — 0.1

†Complete fertilizer 1,000 lbs. of 3 — 8 — 5 — 8 — 2 — 2 — 2

‡Sulphur deficiency symptoms were apparent early in growing season but not at time of harvest.

However, it is now known that the plant physiologists have been in error also in supposing that a three-salt solution merely supplying nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, plus a trace of iron, is capable of meeting the nutrient requirements of plants. Such salt mixtures were effective only because of impurities

they contained. Manganese and boron in relatively minute quantity are now known to be essential for tobacco as well as other crop plants and boron deficiency has been shown to occur in tobacco under field conditions (4). In addition, by means of proper technic applied to solution cultures it has been shown recently that minute quantities of copper and zinc are essential for normal growth of tobacco (5).

As a part of our mineral nutrition research program considerable attention has been given to the rôle of the micro elements in the nutrition of micro-organisms (10). Since a relatively high degree of refinement in technic can be more readily attained in this case, it is of considerable interest to compare the results obtained in solution cultures with the fungus *Aspergillus niger* and with tobacco as a representative of green plants. So far, there has been no indication that boron is essential for Aspergillus and in this connection it may be recalled that in tobacco there is marked similarity in the symptoms of calcium deficiency and boron deficiency and since apparently calcium is not required by Aspergillus it need not be so surprising, perhaps, if boron also is not required. On the other hand, the evidence, though perhaps requiring confirmation, points to the conclusion that molybdenum and gallium are required by Aspergillus (11) and eventually they may be found to be essential for tobacco.

It is thought that the results of the studies briefly outlined above furnish a satisfactory background for a more effective physiological approach to the tobacco fertilizer problem, with special reference to the more tangible phases of the mode of action and the specific functions of the essential elements in the nutrition of the plant. In general, greenhouse cultures cannot be used, for the effects on leaf development of the artificial conditions involved in pot or solution cultures in the greenhouse are so profound that the specific effects of mineral nutrients are obscured or more or less obliterated. Our experience in working in the open indicates it is possible to locate areas of highly siliceous soils which are low enough in content of each of the six macro elements and at least some of the micro mineral elements concerned in nutrition to develop marked and specific deficiency effects in the plant which can be diagnosed with certainty (6). By use of sufficiently pure chemicals on such areas satisfactory material for many features of biochemical and physiological study can be grown and there is the great advantage that the results can be directly correlated with observed effects on the properties of the leaf which are of practical importance in commercial culture. This procedure of course does not lend itself to types of research requiring ultra refinement in purity of the culture medium, but such refinement is of no particular advantage in dealing with the present type of study.

Assuming reasonable uniformity of the soil as culture medium, the principal problem of control of conditions is presented, of course, by variation in the weather. In the nutrition problem under field conditions, especially with respect to mineral absorption and utilization, perhaps the most important weather variable is rainfall. It has been found possible, however, to control largely the water supply on a small scale by means of a water-proof canvas cover over the test plat, which is placed in position only during periods of rainfall, and

to apply, as needed, measured quantities of water by the usual overhead irrigation method. In this way the relation of the water supply to selective absorption of nutrients and their effects on processes of metabolism and leaf growth and development can be studied in detail. It was found, for example, that in comparison with sustained conditions of drought, an approximately optimum moisture supply which doubled leaf area and caused appreciable decrease in weight per unit of area, gave an increased absorption of nitrogen of only 40% but increased potash absorption 160% and that of sulfur (SO_3) nearly 180% (Table 4). In the study of the physiological processes in relation to mineral nutrition our experience has been that ordinarily trends are best developed by making a series of observations at intervals through the growing period. Naturally, repetition for two or more seasons will afford a truer picture of the interrelation of mineral nutrition and metabolism with respect to possible modifying influences of the weather factors other than rainfall. As already stated, the latter can be directly controlled.

Brief reference may now be made to results obtainable in applying plant physiological methods by means of the procedure which has been outlined. The data presented were obtained on Collington loamy sand and sandy loam soils at Upper Marlboro, Maryland. For success of the plan it is essential, of course, that satisfactory absorption of the several essential elements be obtainable. Of special interest in this connection are the results obtained in a comprehensive experiment with potassium applied as sulfate at eight different rates (8) in which a remarkably close approach to a smooth absorption curve was obtained (Fig. 2). In somewhat less extensive tests with calcium and with nitrogen, almost equally satisfactory absorption data were secured. In each instance, the absorption increments for the lower rates of application rather closely approach a linear series, but at higher rates of application the absorption increments fall off rapidly. Observations made separately on leaf and stalk in the case of nitrogen indicate a rather definitely linear relation in the absorption increments for the stalk.

Up to the present, principal attention has been given to the quantity of the nitrogen supply, in the form of nitrate, in its relation to metabolism and other internal processes as associated with growth and development of the plant, and the physical and chemical characteristics of the cured leaf. The rates of nitrogen application were 20, 40, and 80 pounds per acre, with a control treatment, and 60 pounds of phosphoric acid and 40 pounds of potash were uniformly applied, along with adequate provision for calcium, magnesium, and sulfur. The yield data for a 10-year period conformed reasonably well with the requirements of the Mitscherlich equation, but only when the proportionality factor was given a new numerical value to fit the conditions of the test (Fig. 3, A). Throughout the principal growth period there was an increased content of protein, nicotine, and other nitrogen fractions in the leaf as a result of an increase in the nitrogen supply. This increase in assimilated nitrogen was accompanied by a uniformly high water content in the leaf and a decided decrease in content of starch. The consistency of all the results, as obtained at

TABLE 4.—*Effects of water supply on absorption of nutrients, growth, and leaf development in tobacco, Upper Marlboro, Maryland.**

Treatment	Average moisture content of soil, %	Yield of leaf per acre, lbs.	Pounds of plant food recovered per acre (leaf and stalk)							Area of leaves per plant, sq. ft.	Weight of leaf per sq. ft., grams
			Total ash	N	P_2O_5	K_2O	CaO	MgO	SO_3		
No water applied	3.8	530	102	27.7	4.3	39.4	23.0	6.0	3.3	7.75	5.28
½ in. water twice weekly	8.7	1,034	241	38.8	10.5	102.6	43.5	10.4	9.2	15.71	5.08
Natural rainfall	6.7	868	198	42.3	8.9	90.6	31.0	10.2	7.0	14.29	4.89

*Collington sandy loam. Fertilizer per acre 30 pounds N; 60 pounds P_2O_5; 90 pounds K_2O; 84 pounds CaO; 209 pounds SO_3.

frequent intervals during the growth period, is taken to indicate the soundness of the procedure followed and the dependability of the sampling (Fig. 3, B).

In association with the above-mentioned effects of nitrogen supply on internal conditions, the maximum growth rate as measured by increase in height and date of flowering, as well as the narrowest ratio of leaf to stalk and of lamina to midrib in the individual leaf, were

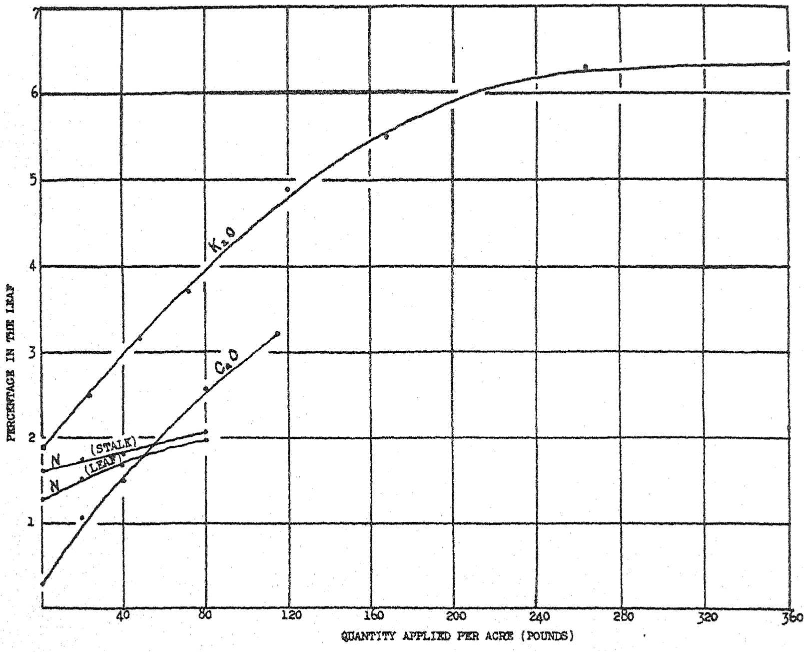

FIG. 2.—Absorption curves, showing increase in percentage content of potash and calcium (CaO) in the leaf and of nitrogen in leaf and stalk, as the rate of application of these elements is increased. The absorption values show in each case a very close approach to a smooth curve, the values for the leaf at lower rates of fertilization tending to form series which are almost linear while at the heavier rates the curves rapidly flatten. Nitrogen absorption values for the stalk form a more definitely linear series.

attained with a moderate nitrogen supply (Table 5). The slow growth caused by nitrogen deficiency resulted ultimately in an increased number of leaves per plant. A high nitrogen supply produced the broadest, largest leaves in association with the high turgor which was uniformly maintained, while, conversely, these leaves were thinnest and lightest in weight per unit of area. The combustibility of the leaf was lowered, presumably because of the increase in protein content.

Results obtained with the cured leaf confirm and amplify the data on the growing plant as indicative of the profound effect of the nitrogen supply on the chemical and physical properties of the leaf (Table 5). In fact, the experimental data as a whole obtained with

Maryland tobacco grown at different levels of nitrogen nutrition furnish a very satisfactory background for the assumption that, with other conditions equal, it is possible by greatly varying the nitrogen supply to change fundamentally the type or class of tobacco produced.

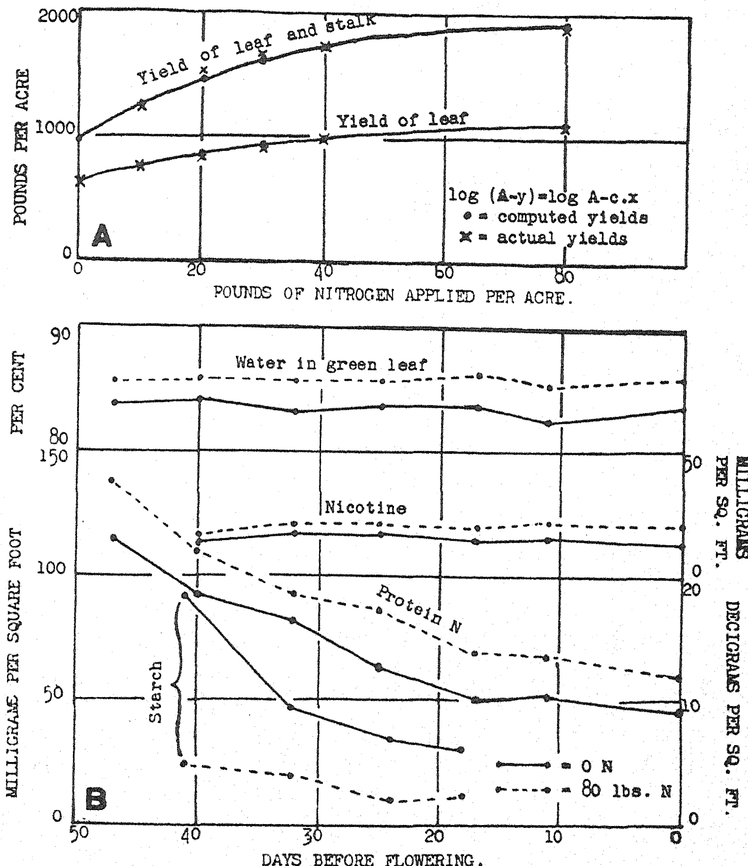

FIG. 3.—Effects of an increased supply of nitrogen on (A) 10-year average yield of leaf and of leaf and stalk combined in relation to the Mitscherlich equation; and (B) content of the growing leaf in protein, nicotine, starch, and water through a period of 46 days preceding the flowering stage. The Mitscherlich equation is applicable only if the numerical value of the proportionality factor (C) is suitably increased. The biochemical data are notably consistent throughout.

Reference is made to the flue-cured and Maryland cigarette types, on the one hand, and to the cigar wrapper leaf, on the other hand. The contrast between the flue-cured and cigar wrapper types in properties of commercial importance is as wide, perhaps, as that between any commercial types produced. The Maryland type is somewhat intermediate as a whole, but in many respects is more nearly like the flue-cured leaf. Much the same type of soil is used in growing the three

TABLE 5.—*Relation of nitrogen supply to growth and development of the tobacco plant, the physical and chemical properties of its leaf, and the commercial type of leaf tobacco produced.*

Measurement	Type of Leaf				
	Flue-cured cigarette leaf with 25–30 lbs. of N per acre	Maryland cigarette leaf, with			Cigar binder and wrapper leaf with 200 lbs. of N per acre
		No treatment	20 lbs. of N per acre	80 lbs. of N per acre	
Growth, Development, and Physical Properties					
Percentage of plants flowering in 70 days	—	38	82.7	81.9	—
Average height at end of 42 days, in.	—	21.0	43.9	44.7	—
Percentages of leaf and stalk, respectively	—	65; 35	59; 41	60; 40	—
Percentage of midrib in leaf	—	27.1	29.3	27.8	—
Average number of leaves per plant	—	34.6	27.2	28.0	—
Average area of leaves, sq. in.	—	96.7	146.0	197.9	—
Ratio of length to width of leaf	—	2.17	2.05	1.88	—
Dry weight of mature leaf per square foot, grams	—	6.05	5.48	4.60	—
Apparent average thickness of leaf, microns	—	500	390	280	—
Combustibility, duration of glow, seconds	—	24.9	9.1	6.0	—
Av. wt. of cured leaf per sq. ft., grams	7.9	4.8	4.3	3.6	2.75–4
Color of cured leaf	Lemon to orange	Yellowish red to reddish brown			Light brown
Chemical Characteristics of Cured Leaf, %					
Protein	6.38	7.50	9.06	11.50	8.23
Amides and amino acids	2.91	1.97	2.47	3.12	8.71
Nicotine	2.25	0.63	0.73	1.46	2.92
Ammonia	0.01	0.08	0.06	0.19	0.55
Nitrate (NO_3)	0.03	0.08	0.08	0.50	3.19
Total N	2.04	1.81	2.18	3.06	4.84
Starch	3.02	4.34	3.34	1.52	0.0
Sugar	10.48	1.80	1.60	0.79	0.21
Cellulose (fiber)	10.80	16.07	17.20	16.60	13.28
Pectin	12.21	16.17	16.71	15.14	9.77
Citric and malic acids	5.11	4.33	5.53	8.68	9.51
Ash	16.00	14.70	12.88	14.96	20.01
Total assimilated nitrogen fraction	11.55	10.18	12.32	16.27	20.41
Starch and sugar	13.50	6.14	4.94	2.31	0.21
Cellulose and pectin	23.01	32.24	33.91	31.74	23.05
Total carbohydrate	36.51	38.38	38.85	34.05	23.26

types of leaf, but the quantity of nitrogen employed for the cigar leaf is about eight times that used for the cigarette types.

Comparison of the Maryland leaf grown experimentally at three different levels of nitrogen fertilization with standard samples of flue-cured and cigar leaf types shows unmistakably in numerous details of chemical as well as physical characteristics a definite trend away from the cigarette type toward the cigar type as the rate of nitrogen fertilization is increased (Table 5). Certain of these contrasts in properties between the different tobaccos, including differences in color, are accentuated by differences in methods of curing. The flue-cured type is rather rapidly dried or cured with artificial heat, while the Maryland and cigar types are subjected to a slow process of curing under natural conditions. Under the latter conditions, there is more extensive hydrolysis of protein and starch and sugar are mostly consumed in respiration. In flue curing, starch is mostly converted into sugar, but consumption of the latter by respiration is relatively slight. As the nitrogen supply is increased, the color tends to change from yellow to brown and the leaf becomes thinner and lighter in weight. There is a definite progressive increase in the several components of the nitrogen fraction and in organic acids and a corresponding decrease in starch and sugar, but the non-plastic carbohydrate is not much affected.

Briefly, the cigar type is characterized by a very high nitrogen fraction and low total carbohydrate fraction, while the reverse relation applies to the two cigarette types. The essential characteristic of the flue-cured leaf is the high sugar content, which frequently runs 20% or more of the dry weight. The Maryland type differs from both the flue-cured and cigar types in its exceptionally high content of non-plastic carbohydrate, cellulose, and pectin. This, however, is primarily a varietal characteristic to be ascribed to heredity. These differences in chemical composition greatly affect not only the physical properties already mentioned, but also others not readily measured, including the so-called body, texture, and elasticity.

Brief reference may be made, finally, to content of nicotine which is the characteristic alkaloid of tobacco. Though increased nitrogen supply tends to increase the nicotine content, the major factors are heredity and the cultural operation known as topping, or disbudding the plant. Removing the upper portion of the plant ordinarily causes a subsequent rapid increase in content of nicotine in the remaining leaves, low and early topping being especially effective (Fig. 4). In a comparative study of high-nicotine and low-nicotine strains of tobacco no correlation was found between protein content and nicotine content during the growing and developmental period. The dark fire-cured and dark air-cured tobaccos are highest in nicotine of any produced in this country, mainly because of the low, early topping practiced, while the Maryland is lowest in nicotine through the combined effects of heredity and high, very late topping.

SUMMARY

In connection with fertilizer experiments conducted in cooperation with several of the tobacco-growing states, the necessity for developing a physiological approach to the tobacco fertilizer problem, more particularly on light sandy and sandy loam soils, was well demonstrated in certain tests with potash salts at the Oxford, N. C., tobacco station which resulted in the discovery in 1923 of magnesium deficiency in these soils, accompanied by characteristic deficiency symptoms in the crop grown on them.

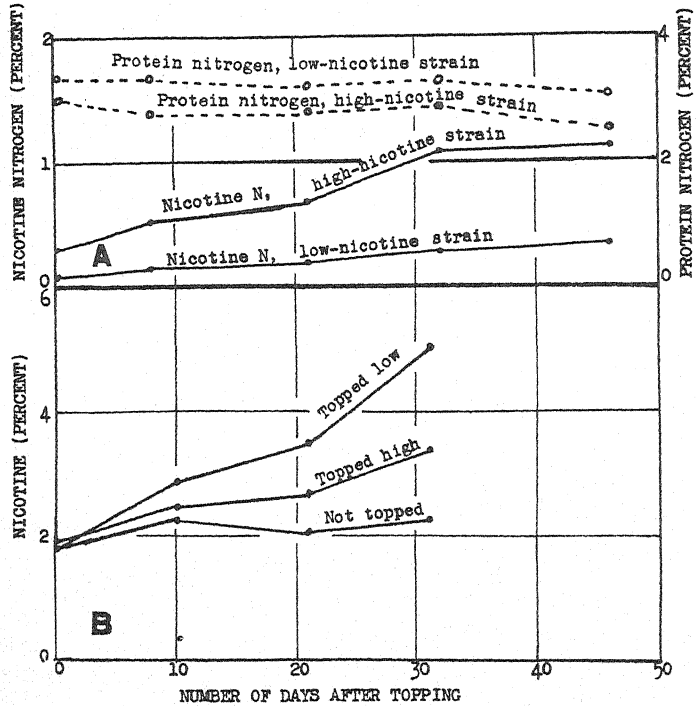

FIG. 4.—A, nicotine content of high-nicotine and low-nicotine strains of the Cuban variety through a period of 47 days after topping. The latter strain failed to accumulate nicotine rapidly in the leaves as normally occurs with ordinary varieties after topping, even though this strain maintained a higher protein content than the high-nicotine strain. B, effect of high topping and low topping on accumulation of nicotine in the leaf, the latter causing a very marked increase in content of alkaloid and emphasizing the potency of this factor.

Chemical analysis of the soils in question and of the tobacco they produce indicates that they are quite as likely to be deficient in calcium, magnesium, and sulfur as in nitrogen, phosphorus, and potassium. Field tests have shown that this is actually the case. In specific cases soil deficiency in all of these six elements has been

demonstrated by (a) marked depression in yield obtained, (b) occurrence in the crop of distinctive deficiency symptoms, and (c) abnormally low content in the crop of the particular element withheld from the fertilizer.

The above-mentioned soils are to be regarded simply as somewhat impure sand culture media and it is not logical, as has been very commonly done in the past, to apply to these soils salts or other substances containing two or more essential elements, without any compensating treatment, and attempt to evaluate the results obtained with plants in terms of only one of the constituent elements.

With soils properly selected with respect to the above-mentioned criteria of mineral deficiency and with the precaution of varying the supply of only a single essential element, excellent data have been obtained on absorption by the plant in relation to increased supply of this element.

Utilizing this plan of conducting "field sand cultures", consistent and significant results have been obtained in extensive physiological studies of effect of the nitrogen supply on growth and development phenomena, metabolism, and other internal relations, and on the chemical and physical properties of the cured tobacco leaf. This appears to furnish a reasonably adequate procedure for study of the more tangible aspects of the mode of action of the essential elements in plant growth and associated phenomena.

LITERATURE CITED

1. GARNER, W. W., MCMURTREY, J. E., JR., BACON, C. W., and MOSS, E. G. Sand drown, a chlorosis of tobacco due to magnesium deficiency, and the relation of sulphates and chlorides of potassium to the disease. Jour. Agr. Res., 23:27–40. 1923.
2. ————, ————, BOWLING, J. D., JR., and MOSS, E. G. Magnesium and calcium requirements of the tobacco crop. Jour. Agr. Res., 40:145–168. 1930.
3. ————, ————, ————, ————. Rôle of chlorine in nutrition and growth of the tobacco plant and its effect on the quality of the cured leaf. Jour. Agr. Res., 40:627–648. 1930.
4. MCMURTREY, J. E. Boron deficiency in tobacco under field conditions. Jour. Amer. Soc. Agron., 27:271–273. 1935.
5. ———— and ROBINSON, W. O. Neglected soil constituents that affect plant and animal development. U. S. D. A. Yearbook, 1938:807–829. 1938.
6. ————. Symptoms on field-grown tobacco characteristic of the deficient supply of each of several essential chemical elements. U. S. D. A. Tech. Bul. 612. 1938.
7. MORGAN, M. F. The soils of Connecticut. Conn. Agr. Exp. Sta. Bul. 320: 825–911. 1930.
8. OJIMA, USHIRO. The growth and the rate of the nutritive absorption of tobacco. Centr. Res. Inst. Gov. Monopoly Bu. [Japan] Sci. Papers, No. 45. 1933.
9. ROBINSON, W. O., STEINKOENIG, L. A., and FRY, WILLIAM H. Variation in the chemical composition of soils. U .S. D. A. Bul. 551. 1917.
10. STEINBERG, ROBERT A. Relation of accessory growth substances to heavy metals, including molybdenum, in the nutrition of *Aspergillus niger*. Jour. Agr. Res., 52:439–448. 1936.
11. ————. The essentiality of gallium to growth and reproduction of *Aspergillus niger*. Jour. Agr. Res. 57:569–574. 1938.

NOTE

HOW SHOULD VARIETIES OF ANNUAL SELF-FERTILIZED CROPS BE PERPETUATED?[1]

THERE are in use today fundamentally different methods for the perpetuation of varieties of annual self-fertilized crops such as wheat. Since the procedure is essentially simple, the existence of widely different treatments to attain the same practical ends invites scrutiny. On the one hand there is the selection of an individual plant as the sole representative of a variety, and on the other the insistence on taking a population-size random sample for this purpose. An examination of the situation should prove interesting.

A variety of a self-fertilized cereal crop is a population of individuals which resemble one another closely in easily observable morphological and qualitative features. The interpretation of this close resemblance varies from the American concept, which separates varieties on the basis of fairly small differences in glume shape, awn length, beak length, spike shape, and so on, to the European concept, which considers such American varieties as Marquis, Kitchener, Red Fife, and Early Red Fife as forms within the same variety. For the purpose of the present discussion, the term "variety" will be considered according to common American usage.

Most varieties in common use are not "pure lines". According to Mendelian principles of inheritance, the progeny of a cross between two plants of a normally self-fertilized species, if continuously self-fertilized for about 20 years without interference from natural crossing or mutation, will consist almost entirely of homozygous plants. Usually a variety of a self-fertilized crop is the increased progeny of an F_5 or F_6 plant. Sometimes a breeder re-selects in F_9 or F_{10}. In either case the increased progeny is actually far from homozygous for many genes governing characters in which uniformity can only be grossly estimated by existing tests. This point has been discussed rather fully by the writer.[2]

The individual plant which is increased and its progeny tested and distributed as a new variety probably would be heterozygous for many genes concerned with milling and baking attributes and other quantitative characters. After this variety has been in use for 10 or 15 years, nearly every plant which has not been affected by natural crossing or mutation would be a pure line. The population would then contain numerous pure lines differing from one another with respect to the above-mentioned genes. In any event the population will be a mixture of biotypes and these constitute the variety which has proved its value to farmers as attested by the extent of its use.

On the supposition that it is better to have a pure line variety, a single plant is removed from the variety in question. This single plant

[1]Written at the suggestion of Prof. E. B. Babcock, Head of Genetics Division, University of California, Berkeley, Calif.

[2]HARRINGTON, J. B. Purity concepts with respect to crop varieties. Sci. Agr., 11:411–417. 1931.

Problems in the development of elite stocks of disease resistant varieties of crops. Ann. Rpt. Can. Seed Growers' Assoc., 59–71. 1937.

may have a gene complex, which gives it the actual average expression of all the characters of the variety, and in this way it is a true and accurate representative of the variety. The chance, however, of any given selection being this particular ideal plant is extremely remote in a crop with the character complexity of wheat, for example. The chances are great, on the other hand, that the single plant selection, while morphologically appearing to represent the variety closely, will be either better or worse than the variety in grain yield, protein content, loaf volume, drought resistance, and various other economically important characters.

Now, if the purpose of making the selection is to improve the variety, a perfectly legitimate breeding problem, it is obvious that *many* selections should be taken, progenies grown, exhaustive tests made, and eventually one of the selections chosen on the basis of these tests to supersede the parent variety.

On the other hand, if the purpose of making the selection is to maintain the existing stock of the variety, also a perfectly legitimate procedure, it is equally obvious that *many* plants will have to be taken. But in this case it is vitally important to take a random sample of the population which constitutes the variety and have that sample large enough to represent the variety accurately. About eight years ago, a group of plant breeders, when confronted with setting an arbitrary minimum size of random sample that would be statistically satisfactory to represent a variety, ruled that such a sample should contain at least 50 plants.

Previous to this time, a large seed growers' association had run into difficulties because it had single plant selection (or pure lining) as one of its methods of producing pure seed of a variety. A number of its members, working with the famous wheat variety Marquis, each selected individual plants, grew their progenies, and selected the best looking one to be his future stock of the variety. Thus arose many strains of Marquis, some of which differed noticeably from the others even in minor morphologic features.[3] After a review of the situation, the association barred "pure lining" as a method of producing a pure stock of a variety on the fundamental grounds that "pure lining" is not a method of maintaining a variety but of improving a variety and therefore was definitely the plant breeder's business.

Then, in order to protect the identity of a variety and at the same time keep it from deteriorating through mixture or disease, the association, in drawing up its new regulations for producing elite stock seed, insisted not only on a minimum random sample of 40 plants, but upon two successive years of progeny tests for the purpose of noting and eliminating any progenies distinctly different in appearance from the norm or average.

The plant breeder often takes individual plant selections from a variety which has become mixed or from a new variety which was bulked in F_4 or F_5. In the latter case, the purpose of the selecting is to improve on the variety, and the selections may show significant

[3]Harrington, J. B. A comparative study of strains of Marquis wheat. Sci. Agr., 8:77–104. 1927. Also unpublished later work of the writer.

differences in many respects. Recent examples are the selections made in Apex wheat at the University of Saskatchewan and Renown wheat at the Dominion Rust Research Laboratory in western Canada.

At many institutions a high degree of homozygosity is maintained in variety stocks for genetic research, through the selection each year, or every few years, of a single apparently representative plant to carry the stock along. This practice is sound, if the selected plant is protected from natural crossing. But it must be kept in mind that the results of the research apply strictly to the stock used and only approximately to the variety from which the stock was derived. It may be noted further that the desire for genetic purity in such a stock is in no way indicative of a need for such a high degree of homozygosity in a commercial variety.

Although seed growers' organizations appear to aspire to higher and higher purity in their cereal stocks, it cannot be said that in practice they seek genetic purity or have need of it. It has never been proved that a homozygous stock in a normally self-fertilized species is superior to one slightly less homozygous but otherwise similar. And there are many people who are against having extremely high purity in such material. One of their arguments is that heterosis is reduced to nothing as compared with something; another one is that a mixture of biotypes should be more adaptable than a single pure line to the various environments encountered in any given location; and a third is that since complete homozygosity is almost nonexistent in nature, it is working against nature to render a variety homozygous.—J. B. HARRINGTON, *University of Saskatchewan, Saskatoon, Canada.*

AGRONOMIC AFFAIRS

DOCTOR J. G. LIPMAN

DOCTOR J. G. LIPMAN, Dean of the New Jersey College of Agriculture and Director of the New Jersey Agricultural Experiment Station, died on Wednesday, April 19, following a brief illness.

Doctor Lipman was a charter member of the American Society of Agronomy and until his death was actively identified with the Society in various capacities. He was elected a Fellow of the Society in 1926 and in 1927 served as a member of the American Organizing Committee for the First International Congress of Soil Science which was held in Washington, D. C., in June of that year. He was later elected President of the Executive Committee of the Congress. At the time of his death he was lending very substantial aid in perfecting arrangements for the meeting of the Third Commission of the International Society of Soil Science which is to meet in New Brunswick in August.

A more complete account of Doctor Lipman's life and contributions to agronomy will appear in a later issue of this JOURNAL.

JOURNAL

OF THE

American Society of Agronomy

VOL. 31 JUNE, 1939 No. 6

TILLERING ABILITY OF SORGHUM VARIETIES[1]

J. B. SIEGLINGER AND J. H. MARTIN[2]

CULTIVATED varieties of sorghum differ widely in the number of tillers or "suckers" normally produced by a plant. Within a variety, tillering is influenced by environmental factors, such as plant spacing, soil moisture, soil fertility, temperature, growing period, date of planting, and stage at which the soil is thrown into lister furrows covering the bases of the plants. All sorghum plants normally bear a bud at each of the 8 to 10 underground nodes in the crown. Each of these buds might eventually produce a tiller under proper stimuli and suitable growing conditions, but rarely do all tillers produce buds in a single growing season.

The ability of a sorghum plant to produce more than one stalk has been recognized by botanists and sorghum growers since the species was first described. Varietal differences in tillering have been noted by many agronomists, some of whom, including Ball and Rothgeb (1),[3] Sieglinger (9), Karper, *et al.* (5), and Quinby, *et al.* (8), have presented data on the relative tillering of a considerable number of varieties. The effect of spacing on tillering in milo was shown by Hastings (3).

The ability or tendency to produce more than one stalk often is of practical importance in enabling the plant to take advantage of surplus space, moisture, and plant food. Agronomists differ, however, in opinion regarding the general desirability of tillering in sorghums. Studies by Sieglinger (10), Karper (4), Martin, *et al.* (7), and Karper, *et al.* (5) to determine the best spacing for sorghum plants have indicated that the optimum spacing depends upon the tillering habit of the variety and that varieties which tiller poorly should be planted relatively thick. With the recognition of this relationship, a study of varietal differences in the tillering ability of sorghums was begun in 1930 at the Southern Great Plains Field Station, Woodward, Okla. A varying but representative collection of all important sorghum groups and including 150 or more varieties has been grown in single rows at that station for several years for observation and for the maintenance of breeding stocks. In order to facilitate the study of

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication January 20, 1939.
[2]Agronomist and senior agronomist, respectively.
[3]Numbers in parenthesis refer to "Literature Cited", p. 488.

tillering behavior, half of each row was thinned to a spacing of about 3 feet between plants and the remainder, where possible, to a plant spacing of 6 inches. Stalk and plant counts recorded on each half of the row furnish the basis for the data presented here.

MATERIALS, METHODS, AND SEASONAL CONDITIONS

The miscellaneous sorghum varietal nursery at Woodward consisted of single 132-foot rows, 3½ feet apart, of standard varieties and many newly developed or introduced varieties of both grain and forage types. The varieties and selections were grouped in the nursery according to their agronomic classification. All varieties were planted on a single day, between June 11 and June 16 each year, and the plants emerged four to six days later. The planting was always thicker than necessary to produce the desired stand under usual conditions. Thinning to the desired spacing was done by hand during July when the plants were 3 to 5 inches tall. Half of each row (66 feet) was thinned to approximately one plant each 36 inches in the row, while in the remainder of the row the plants were spaced as nearly as possible to one plant every 6 inches. It was difficult to approximate a 6-inch spacing because of differences in germination, seedling survival, and seed size, and an average actual spacing of about 7.4 inches was secured. The number of plants in each half row was determined soon after thinning and the stalks were counted at the end of the growing season. A tiller over 6 inches or more in height was counted as a stalk, but shorter tillers were disregarded. In favorable seasons a high percentage of all stalks produced heads and grain, but in severe years even the main stalks of many varieties did not produce heads.

There were wide varietal variations in tillering in different years in both thin and thick spacings. A brief statement of the chief seasonal weather conditions influencing sorghum growth therefore is presented. In 1930 a drought extended from the second week of June to the third week of August, but tillering and vegetative growth were stimulated by moisture that became available in late August, September, and early October.

The growing season of 1931 started favorably, but hot, dry periods followed at intervals during the summer months. Intermittent rains caused some varieties of sorghum to develop numerous tillers in the thin spacing. Sorghum yields were near the average. The 1932 season was characterized by excessive precipitation in June and no effective rain in July, but a rainy period in August resulted in yields of sorghums above average.

The sorghum nursery was not planted in 1933 because a drought from the first of May until the middle of July caused planting to be postponed until too late. The season of 1934 was hot and dry from the middle of June to the middle of August and sorghum yields were very low. Certain early-maturing varieties only were planted. In 1935 precipitation was low in the summer months and sorghum yields were only about 50% of the average. The 1936 season was the worst in the history of the station (23 years). No effective rain occurred from the first week of June until the first week of September. High temperatures and low humidity prevailed throughout the summer and sorghum yields were practically zero. In 1937 conditions were rather favorable at planting time but drought and high temperatures followed. Rains came in late August and September. Fair yields of most varieties were obtained.

RESULTS OBTAINED

The annual and average number of stalks per plant of the varieties in thick and thin spacings is shown in Table 1. The average number of tillers, or suckers, per plant may be computed by subtracting one from the number of stalks per plant. A total of 86 varieties and strains was grown and data recorded in each of six years and four or five years' data from 19 additional varieties also are included. Some of these 19 varieties were grown in other years, but owing to poor stands and the consequent irregular tillering the data for these years are not shown. Averages are shown for the varieties grown less than six years in order to permit general comparisons despite the fact that the data are not fully comparable. Seasonal variations in the rank of the varieties were common, but in most cases the average relative tillering of the varieties was of similar order whether 4, 5, or 6 years' data were included. Only a few early varieties were grown in 1934 and the data for that year are not included in the varietal averages except in the case of a few varieties not grown in 1930 and 1931.

The average space per plant in the thick spacing (Table 1) is about 7.4 inches. The average thin spacing attained was sufficiently close to the 36 inches desired, except in Blackhull kaoliang and Freed, so that the relative number of stalks per plant shown is reasonably accurate in most varieties. Varieties that tillered heavily were affected but slightly by variations from the 36-inch spacing.

The range of the varieties in the thick spacing, with average extreme distances between plants of 5.7 to 10.3 inches, probably accounts to a considerable extent for the variation in tillering that does not correspond to the rank of the varieties in tillering in the thin spacing.

The six seasons differed somewhat in the average number of tillers produced by the 79 varieties in the recognized groups grown each of the six years. In average annual number of tillers in the thin spacing the seasons ranked in descending order as follows: 1932, 1937, 1936, 1931, 1935, and 1930. The various groups followed the general trend only in part. It will be observed that most varieties produced at least a few tillers regardless of spacing or season, although some did not tiller even in the thin spacing in certain years. Extremes in tillering in the thin spacing ranged from none (one stalk per plant) for several varieties in various seasons to 5.8 (6.8 stalks per plant) in feterita (C. I. 693) in 1936, with a spacing of 39.6 inches.

The average number of stalks per plant in the various sorghum groups given in Table 1 is shown more effectively in Fig. 1.

The hegari group, consisting of only two varieties grown five years, showed the highest tillering capacity, having produced 3.23 tillers (4.23 stalks) per plant in the thin spacing and 1.03 tillers per plant in the thick spacing. Durras showed the least tendency to tiller and the kafirs tillered only slightly more. The number of tillers per plant in the thick spacing followed the same order by groups as in the thin spacing except in the case of sorgo, in which tillering in the thick spacing was low proportionally. This discrepancy apparently

TABLE 1.—*Annual and average number of stalks per plant and average plant spacing of 105 sorghum varieties grown at Woodward, Okla., in thick and thin spacings.*

Variety	C. I.[1] No.	Number of stalks per plant																Average plant spacing, inches	
		1930		1931		1932		1934		1935		1936		1937		Six-year average			
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Milo																			
Dwarf Yellow	332	1.32	3.57	1.40	4.59	1.40	3.61	—	—	2.41	4.24	1.48	1.30	1.46	2.64	1.59	3.33	7.9	36.1
Dwarf Yellow	359	1.35	2.78	1.58	4.13	1.75	4.18	—	—	1.87	3.09	1.35	1.35	1.58	3.09	1.60	3.10	7.9	35.2
Double Dwarf	868	1.44	3.36	1.39	4.35	2.06	3.35	—	—	2.11	3.32	1.38	1.61	1.58	2.00	1.66	3.00	7.5	35.2
Dwarf White	627	1.13	2.71	1.73	4.29	1.50	4.18	—	—	1.90	3.55	1.25	1.77	1.55	2.81	1.51	3.22	7.0	36.1
Early White	480	1.09	1.57	1.46	3.13	1.64	3.65	1.16	1.73	1.38	3.41	1.20	1.59	1.17	2.64	1.32	2.67	7.8	35.5
Standard Yellow	234	1.23	1.95	1.27	3.44	1.37	3.62	—	—	1.29	2.64	1.29	1.59	1.46	3.23	1.32	2.75	7.7	34.8
Standard White	352	1.16	2.20	1.48	3.57	1.24	3.55	—	—	1.58	3.05	1.22	1.67	1.47	3.09	1.36	2.86	7.6	35.8
Sooner	917	1.13	2.55	1.36	3.08	1.34	3.86	1.09	2.17	1.25	2.55	1.52	2.52	1.49	3.05	1.36	2.94	8.4	36.1
Sooner (Chillicothe) F. C. 8975[2]	—	—	—	—	—	—	—	1.63	2.91	1.60	3.87	1.21	2.09	1.35	3.62	1.45[3]	3.12[3]	6.9	35.6
Sooner (Lubbock)	—	—	—	—	—	—	—	1.11	2.47	1.50	3.57	1.56	2.82	1.35	3.23	1.38[3]	3.02[3]	7.4	37.1
480 x 332-16	962	1.44	2.67	1.30	2.65	1.29	2.91	1.41	2.52	1.14	2.52	1.56	2.05	1.80	4.23	1.42	2.84	7.3	35.7
Day	959	—	—	—	—	1.55	2.78	1.12	1.46	1.46	1.60	1.57	2.23	1.34	1.82	1.41[4]	1.98[4]	8.7	33.3
Pygmy	1010	—	—	—	—	1.46	2.50	1.35	2.79	1.18	1.83	1.52	3.00	1.21	1.41	1.34[4]	2.31[4]	8.9	33.9
Average (9 varieties)	—	1.25	2.60	1.44	3.69	1.51	3.66	—	—	1.66	3.15	1.36	1.72	1.51	2.98	1.46	2.97	7.7	35.6
Milo-kafir Derivatives																			
Wheatland	918	1.08	1.55	1.62	2.55	1.37	3.00	1.21	2.26	1.00	2.71	1.16	1.76	1.36	2.10	1.27	2.28	7.4	36.9
Wheatland backcross	—	—	—	1.74	3.09	1.56	3.05	—	—	1.17	3.17	1.58	3.48	2.53	3.73	1.72[4]	3.30[4]	8.1	36.0
Smith milo x kafir	808	1.03	1.10	1.06	1.63	1.10	1.50	1.00	1.00	1.01	1.00	1.03	1.25	1.10	1.05	1.06	1.26	7.9	35.0
Fargo	809	1.04	1.05	1.17	2.07	1.49	2.36	—	—	1.16	1.32	1.02	1.04	1.11	1.14	1.17	1.50	7.8	34.9
Desert maize	—	1.20	1.50	1.67	2.87	1.47	2.59	—	—	1.83	1.83	1.17	1.05	1.39	2.18	1.46	2.00	9.5	35.2
Manko	—	1.00	1.10	1.18	1.96	1.13	3.71	—	—	1.05	1.25	1.08	1.09	1.26	1.73	1.12	1.81	7.3	35.8
Kalo	902	1.06	1.15	1.18	1.88	1.14	2.73	—	—	1.16	2.33	1.01	1.14	1.27	2.18	1.14	1.90	6.4	35.9
Early kalo	1009	—	—	—	—	—	—	1.41	3.08	1.15	2.04	1.00	1.00	1.21	2.19	1.19[3]	2.08[3]	6.3	34.6
Custer	919	1.04	1.09	1.00	1.04	1.20	1.82	—	—	1.04	1.36	1.01	1.55	1.19	1.36	1.08	1.37	6.5	36.1
Beaver	871	1.02	1.21	1.15	1.88	1.19	2.26	1.16	2.08	1.14	1.57	1.00	1.18	1.46	2.05	1.16	1.69	7.0	34.2
A x 332-6	961	1.04	1.00	1.13	2.09	1.24	1.77	1.22	1.11	1.04	2.17	1.06	1.48	1.28	1.61	1.13	1.69	6.5	35.5
A x 332-31-79	960	1.02	1.24	1.33	1.88	1.05	2.36	1.06	1.38	1.05	1.63	1.23	1.23	1.10	1.41	1.13	1.63	7.5	35.1
Kafir x milo-8-2-6	1090	1.02	1.13	1.03	1.04	1.01	1.70	1.44	1.58	1.04	1.16	1.15	1.30	1.26	1.14	1.09	1.25	8.1	34.0
Kafir x milo-38-1-2-1	970	1.02	1.17	1.15	1.67	1.14	2.23	1.33	2.08	1.00	1.64	1.14	1.91	1.19	1.36	1.11	1.66	7.3	35.2
Bishop	814	1.04	2.29	1.82	2.24	1.13	3.17	—	—	1.39	2.48	2.02	4.14	1.68	3.76	1.51	3.01	8.0	35.3
Average (13 varieties)	—	1.05	1.28	1.27	1.91	1.20	2.40	—	—	1.15	1.73	1.16	1.55	1.28	1.77	1.19	1.77	7.5	35.3

Kafir																			
Blackhull	71	1.04	1.19	1.00	1.25	1.03	2.50	—	—	1.01	1.28	1.17	1.82	1.01	1.41	1.04	1.58	5.8	35.1
Blackhull	204	1.00	1.14	1.02	1.17	1.05	2.76	—	—	1.05	1.05	1.14	1.96	1.59	1.32	1.14	1.57	7.7	36.1
Sharon Blackhull	813	1.02	1.29	1.02	1.04	1.04	2.62	—	—	1.00	1.14	1.09	1.95	1.01	1.73	1.03	1.63	5.8	37.3
Texas Blackhull	865	1.00	1.00	1.04	1.00	1.01	2.62	—	—	1.03	1.00	1.15	1.70	1.24	1.43	1.08	1.46	7.1	36.4
Western Blackhull	906	1.01	1.19	1.06	1.04	1.01	2.18	—	—	1.00	1.14	1.07	1.45	1.53	1.25	1.11	1.38	8.5	36.6
Santa Fe No. 1	—	1.02	1.33	1.02	1.00	1.03	2.09	—	—	1.05	1.09	1.18	2.05	1.01	1.50	1.05	1.51	6.1	36.3
Reed	628	1.02	1.38	1.05	1.48	1.02	2.73	—	—	1.11	1.30	1.17	3.09	1.14	2.65	1.09	2.11	7.3	35.5
Hydro	1023	1.04	1.57	1.12	1.33	1.04	2.77	—	—	1.03	1.27	1.55	2.91	1.21	2.23	1.17	2.01	6.7	36.6
Rice	—	1.00	1.18	1.14	1.17	1.00	3.38	—	—	1.05	1.91	1.22	2.18	1.11	2.63	1.09	2.08	6.6	36.0
Pearl	—	1.18	1.79	1.05	1.35	1.00	2.87	—	—	1.05	1.24	1.35	2.70	—	—	1.13[4]	1.99[4]	7.8	35.3
Corneous (local)	—	1.01	1.05	1.00	1.00	1.03	1.61	—	—	1.03	1.00	1.17	1.21	1.03	1.18	1.05	1.18	7.3	36.7
Dawn selection	904	1.03	1.68	1.16	1.46	1.00	2.50	—	—	1.15	2.10	1.37	1.30	—	—	1.14[4]	1.81[4]	6.1	34.9
Dawn	340	1.01	1.59	1.08	2.13	1.00	2.32	—	—	1.14	1.56	1.15	1.24	1.07	1.82	1.08	1.78	5.7	35.3
Sunrise	472	1.07	2.38	1.33	3.36	1.13	3.68	—	—	1.37	2.84	1.93	3.48	1.40	3.76	1.37	3.25	5.9	35.8
Marum	566	1.07	1.24	1.05	1.08	1.00	3.00	—	—	1.00	1.09	1.27	1.85	1.04	2.18	1.07	1.74	6.0	36.2
White	370	1.04	1.10	1.04	1.10	1.00	1.50	—	—	1.06	1.04	1.21	1.18	1.05	1.82	1.07	1.29	6.9	36.1
Pink	432	1.03	1.14	1.00	1.04	1.00	2.48	—	—	1.01	1.23	1.16	1.14	1.06	1.43	1.04	1.41	6.3	36.6
Early Red	866	1.07	1.10	1.10	1.04	1.00	1.74	—	—	1.01	1.00	1.11	1.10	1.05	1.18	1.06	1.19	6.6	36.1
Red (No. 7)	—	1.04	2.43	1.43	2.50	1.01	3.48	—	—	1.25	1.96	1.71	3.33	1.29	3.41	1.29	2.85	7.0	36.1
Red	34	1.03	1.20	1.04	1.09	1.01	1.55	—	—	1.00	1.00	1.21	1.18	1.23	1.50	1.09	1.25	9.5	37.2
African	663–II	1.05	1.29	1.05	1.10	1.00	1.45	—	—	1.00	1.00	1.21	1.32	—	—	1.06[4]	1.23[4]	6.8	37.0
Average (18 varieties)	—	1.03	1.36	1.09	1.38	1.02	2.50	—	—	1.07	1.33	1.26	1.93	1.17	1.91	1.11	1.74	6.8	36.2
Kafir-feterita Derivatives																			
Wonder	872	1.04	2.05	1.29	1.82	1.04	2.45	—	—	1.97	2.45	1.30	2.76	1.15	2.95	1.15	2.41	6.2	36.6
Club	901	1.04	3.00	1.85	3.83	1.11	3.83	—	—	1.70	3.52	1.74	3.86	—	—	1.49[4]	3.61[4]	7.8	35.5
Premo	873	1.08	1.27	1.03	1.43	1.18	2.41	—	—	1.27	1.65	1.31	3.23	1.23	2.59	1.18	2.10	7.1	36.0
Chiltex	874	1.06	2.71	1.10	2.00	1.39	3.45	—	—	1.28	1.83	1.38	3.43	1.59	3.09	1.30	2.75	7.2	35.8
Ajax	968	1.00	1.95	1.02	1.87	1.21	3.14	—	—	1.28	2.50	1.60	3.86	1.52	2.91	1.27	2.71	6.2	36.0
Kaferita	811	1.07	2.00	1.02	1.79	1.19	3.22	—	—	1.25	1.91	1.29	3.19	1.26	2.86	1.18	2.50	8.9	35.3
Kaferita	812	1.14	2.81	1.07	2.13	1.74	3.73	—	—	2.06	2.75	1.91	3.74	2.90	3.45	1.80	3.10	10.2	35.3
Dwarf Brown kaferita	—	1.15	2.57	1.08	2.48	1.37	3.86	—	—	1.39	2.41	1.63	3.40	1.60	3.24	1.37	2.99	7.0	36.9
Average (7 varieties)	—	1.08	2.19	1.09	1.93	1.30	3.18	—	—	1.37	2.21	1.49	3.37	1.61	3.01	1.32	2.65	7.5	36.0
Feterita																			
Standard	182	1.67	3.52	1.90	4.08	1.45	5.05	1.99	4.84	1.26	3.39	1.87	5.00	2.41	4.61	1.76	4.28	8.6	35.3
Spur	623	1.08	2.62	2.01	2.73	1.26	3.41	—	—	1.38	2.56	1.16	2.71	—	—	1.38[4]	2.81[4]	8.3	34.7
Dwarf	810	1.08	1.78	1.35	2.08	1.00	1.61	—	—	1.02	1.52	1.44	3.86	1.20	2.73	1.18	2.26	8.0	36.6
Hybrid Dwarf	867	1.98	3.00	2.06	3.43	1.32	2.86	2.23	4.60	1.50	3.19	1.48	3.53	1.84	3.43	1.70	3.24	9.9	37.3
———	693	2.02	4.24	2.01	4.88	1.65	5.09	3.04	4.87	1.35	3.83	2.34	6.80	2.36	5.86	1.96	5.12	9.2	35.9
Red	693–R	1.06	2.78	1.45	3.65	1.47	3.96	—	—	1.80	3.17	1.96	4.57	1.74	3.38	1.58	3.59	7.4	35.8
———	745	2.77	4.55	2.31	5.92	2.08	5.30	2.97	3.45	1.71	3.69	2.32	4.81	1.98	4.19	2.20	4.74	8.8	34.4
———	749	1.61	3.18	1.57	3.61	1.25	4.17	2.09	3.57	1.15	3.38	1.68	4.81	1.81	3.68	1.51	3.81	7.8	35.8
White	755	2.62	4.91	1.73	4.69	2.01	4.70	2.26	4.64	1.62	4.14	2.82	6.76	2.42	6.05	2.20	5.21	8.5	35.1
Average (8 varieties)	—	1.85	3.50	1.80	4.04	1.53	4.09	—	—	1.43	3.29	1.99	5.02	1.97	4.24	1.76	4.03	8.5	35.8

[1]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
[2]Accession number of the Division of Forage Crops and Diseases.
[3]Four-year average.
[4]Five-year average.
[5]Accession number of the Division of Plant Exploration and Introduction, for Office of Seed and Plant Introduction.
[6]Includes the varieties in all groups (except miscellaneous) grown in all six years.

TABLE I.—*Concluded.*

Variety	C. I.[1] No.	Number of stalks per plant																Average plant spacing, inches	
		1930		1931		1932		1934		1935		1936		1937		Six-year average			
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Durra																			
Early Dwarf S. P. I. 57045[5]	—	1.11	2.59	1.17	1.70	1.42	2.32	1.15	2.14	1.00	1.44	1.17	2.00	1.20	1.71	1.18	1.96	6.6	35.6
Standard White	978	1.01	1.43	1.08	1.09	1.21	1.39	1.03	1.21	1.00	1.00	1.09	1.09	1.08	1.05	1.08	1.18	7.8	35.8
White (erect)	81	1.02	2.74	1.04	1.78	1.16	2.62	1.04	1.93	1.00	1.16	1.20	1.27	1.12	1.14	1.09	1.79	7.3	37.0
Corneous	695	1.06	1.10	1.08	1.17	1.40	1.75	—	—	1.09	1.62	1.09	1.54	1.21	1.23	1.16	1.40	10.3	35.3
"Pig-nose"	696	1.03	1.05	1.05	1.00	1.11	1.05	—	—	1.00	1.00	1.03	1.00	1.05	1.00	1.05	1.02	9.5	35.3
Average (5 varieties)	—	1.05	1.78	1.08	1.35	1.26	1.83	—	—	1.02	1.24	1.12	1.38	1.13	1.23	1.11	1.47	8.3	35.8
Hegari																			
Dwarf	620	1.27	3.19	—	—	1.89	3.67	—	—	1.71	3.33	2.42	4.82	2.70	4.86	2.00[4]	3.97[4]	7.5	37.1
Dwarf	750	1.27	4.44	—	—	1.89	3.73	—	—	2.21	4.09	2.51	5.18	2.38	4.96	2.05[4]	4.48[4]	6.9	36.8
Average (2 varieties)	—	1.27	3.82	—	—	1.89	3.70	—	—	1.96	3.71	2.47	5.00	2.54	4.91	2.03[4]	4.23[4]	7.2	37.0
Kaoliang																			
Blackhull	310	1.17	3.10	1.23	4.26	1.66	5.39	1.89	2.95	1.46	3.58	1.83	4.00	1.80	4.27	1.53	4.10	6.6	42.0
White	636	1.01	2.95	1.40	2.86	1.76	4.09	—	—	2.05	2.81	1.80	3.15	1.37	2.86	1.57	3.12	9.1	35.8
White	792	1.02	1.14	1.07	1.14	1.33	3.45	—	—	1.56	2.52	1.15	1.95	1.05	1.43	1.20	1.94	7.8	36.1
White S. P. I. 46676[5]	—	1.00	1.11	1.11	1.38	1.21	2.27	1.01	1.11	1.08	1.35	1.08	1.27	1.02	1.18	1.08	1.43	8.3	36.7
Shantung	293	1.04	1.00	1.00	1.17	1.09	2.27	—	—	1.00	1.05	1.05	1.09	1.03	1.00	1.04	1.26	7.3	35.5
Manchu Brown	171	1.00	1.00	1.00	1.30	1.21	2.18	1.00	1.26	1.05	1.33	1.02	1.05	1.00	1.09	1.05	1.33	8.0	36.3
Valley	309	1.02	1.61	1.08	2.52	1.43	3.73	1.22	1.43	1.15	3.14	1.27	2.89	1.27	2.33	1.20	2.70	6.4	37.4
Early	791	1.00	1.71	1.03	2.48	1.33	3.00	1.07	2.39	1.01	2.32	1.13	2.14	1.01	1.29	1.09	2.16	7.1	36.9
Brown S. P. I. 46677[5]	—	1.03	1.62	1.03	1.61	1.27	3.57	1.00	1.37	1.10	1.65	1.14	1.75	1.04	1.09	1.10	1.88	6.1	35.2
Broom	799	1.00	1.00	1.09	1.00	1.08	1.52	1.00	1.10	1.04	1.00	1.15	1.14	1.02	1.00	1.06	1.11	7.4	36.1
Average (10 varieties)	—	1.03	1.62	1.10	1.97	1.34	3.15	—	—	1.25	2.08	1.26	2.04	1.16	1.75	1.19	2.10	7.4	36.8

Miscellaneous Grain Sorghums																			
Shallu	85	1.18	3.57	1.66	3.38	1.26	4.45	—	—	1.67	3.26	2.10	3.23	2.22	6.00	1.68	3.98	6.4	35.8
Darso	615	1.05	1.09	1.00	1.00	1.00	1.86	1.00	1.08	1.01	1.04	1.06	1.10	1.02	2.00	1.02	1.35	6.3	35.8
Schrock	616	1.13	2.38	1.09	1.41	1.00	2.18	—	—	1.01	1.18	1.70	2.86	1.40	2.27	1.22	2.05	6.8	36.6
Sagrain	—	1.15	2.62	1.26	2.58	1.05	1.83	—	—	1.01	1.81	1.74	2.65	1.68	3.00	1.32	2.42	6.1	36.4
Grohoma	920	—	—	1.10	2.43	1.00	2.33	—	—	1.08	2.36	1.64	3.57	1.31	3.14	1.23[4]	2.77[4]	7.0	35.8
Dwarf Freed	971	1.45	3.57	1.61	3.39	1.19	2.68	1.60	4.26	1.05	2.32	1.35	3.20	1.29	3.45	1.32	3.10	6.7	36.6
Freed	350	1.39	3.25	2.00	4.00	1.41	3.27	2.53	4.13	1.57	2.64	1.52	3.57	1.51	3.55	1.57	3.38	7.5	46.5
Kansas Orange x milo	894	1.08	1.18	1.15	2.04	1.17	2.00	1.00	1.41	1.02	1.42	1.03	1.13	1.19	1.27	1.11	1.51	7.5	34.7
Sorgo																			
Early Amber	—	1.29	4.25	1.48	4.04	1.44	3.91	2.18	5.14	1.47	2.95	2.48	4.86	2.26	4.55	1.74	4.09	6.8	36.9
Black Amber F. C. 7038[2]	—	1.05	3.24	1.23	4.05	1.02	2.83	1.26	4.36	1.04	2.19	2.04	4.17	1.50	4.10	1.31	3.43	7.2	36.1
Red Amber F. C. 9092[2]	—	1.17	2.81	1.20	3.35	1.11	3.33	—	—	1.07	3.24	1.59	4.35	—	—	1.23[4]	3.42[4]	6.4	36.5
Leoti	—	1.11	2.57	1.36	2.13	1.06	2.22	—	—	1.01	1.62	1.27	2.23	1.32	2.27	1.19	2.17	7.7	36.1
Orange (Cron)	—	1.07	1.90	1.19	2.17	1.03	2.04	1.11	2.17	1.06	1.73	1.15	1.79	1.12	2.32	1.10	1.99	6.6	35.3
Kansas Orange	—	1.06	2.90	1.26	2.91	—	—	—	—	1.10	2.29	1.44	3.19	1.33	2.91	1.24[4]	2.84[4]	6.1	36.6
Colman	—	1.17	2.91	1.39	4.42	1.03	3.77	—	—	1.12	3.33	1.76	4.41	1.26	4.18	1.29	3.84	6.5	35.8
Sourless F. C. 9111[2]	—	1.09	3.24	1.38	4.70	—	—	—	—	1.18	3.52	1.74	4.41	1.64	4.68	1.41[4]	4.11[4]	5.9	36.3
African Millet	—	1.06	2.24	1.24	4.32	1.08	3.50	—	—	1.12	3.10	1.39	3.43	1.28	3.53	1.20	3.35	6.2	37.8
Early sumac	—	1.07	2.62	1.36	3.09	1.09	2.27	—	—	1.24	2.62	1.16	2.35	1.34	2.05	1.21	2.50	6.0	36.9
Sumac F. C. 1712[2]	—	1.09	3.19	1.50	4.04	1.17	3.55	—	—	1.08	2.00	2.00	4.30	1.69	4.00	1.42	3.51	5.9	38.0
Sumac S. P. I. 63715[5]	—	1.09	3.10	1.27	4.35	1.16	4.05	—	—	1.25	2.95	1.85	4.24	1.80	4.62	1.40	3.89	6.2	37.2
Collier	—	1.09	2.57	1.12	2.78	1.03	3.35	—	—	1.10	2.00	1.76	2.67	—	—	1.22[4]	2.67[4]	9.2	36.6
Atlas	899	1.24	3.25	1.20	3.35	—	—	—	—	1.72	2.92	2.00	3.68	1.44	3.45	1.52[4]	3.33[4]	6.7	35.6
Average (9 varieties)	—	1.11	2.89	1.34	3.62	1.12	3.13	—	—	1.15	2.50	1.68	3.53	1.51	3.51	1.32	3.20	6.6	36.7
Grand average (79 varieties)[6]	—	1.16	2.01	1.26	2.38	1.25	2.95	—	—	1.24	2.10	1.39	2.45	1.38	2.46	1.28	2.39	7.4	36.0

[1]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
[2]Accession number of the Division of Forage Crops and Diseases.
[3]Four-year average.
[4]Five-year average.
[5]Accession number of the Division of Plant Exploration and Introduction, for Office of Seed and Plant Introduction.
[6]Includes the varieties in all groups (except miscellaneous) grown in all six years.

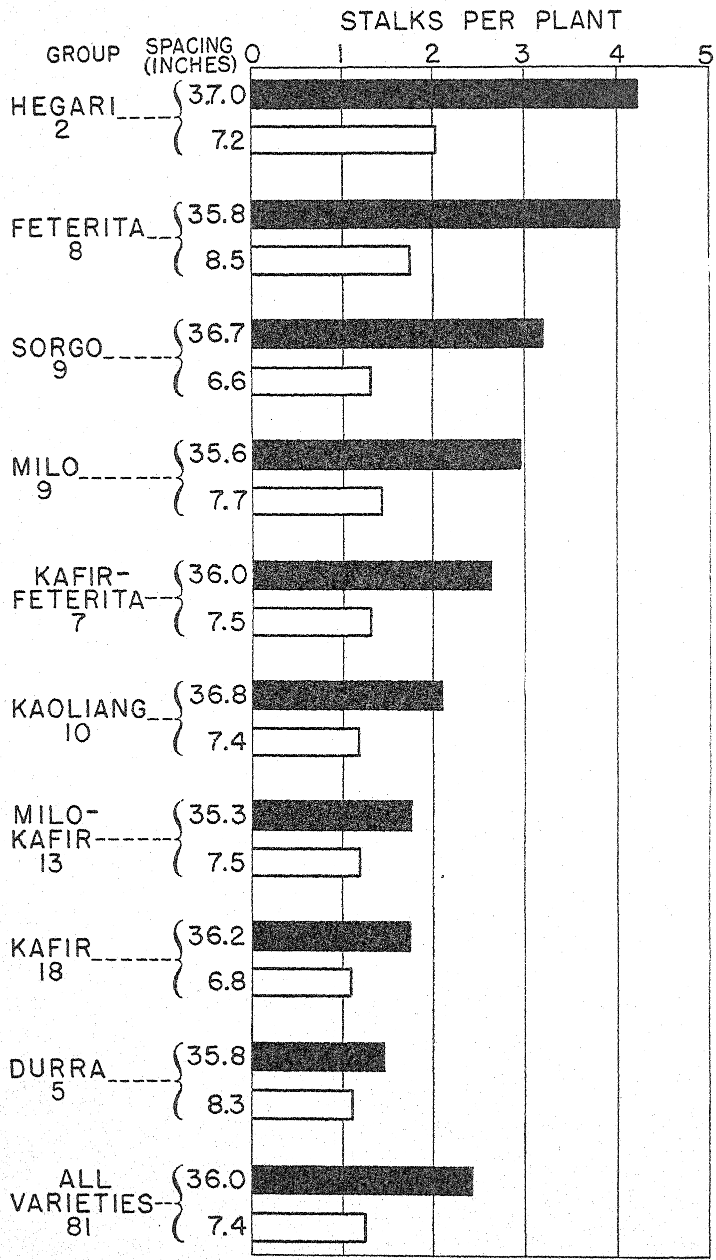

FIG. 1.—Average number of stalks per plant in thick and thin spacing in nine sorghum groups and the average for 81 varieties.

is due to the thicker average spacing of sorgo (6.6 inches) as compared with those of feterita (8.5 inches) and milo (7.7 inches). Sorgos ordinarily are spaced rather thickly in order to secure maximum forage yields, and their generally high tillering capacity as shown in the thin spacing often has not been evident in ordinary field experiments.

Varieties selected from crosses between kafir and feterita tended to be intermediate between the parental types in tillering ability. Varieties selected from kafir-milo hybrids, on the other hand, tended to approach the kafir parent in tillering ability. In this group only the Wheatland backcross and Bishop tended to approach the Dwarf Yellow milo parent in the number of tillers produced.

The average number per plant among the 79 sorghum varieties grown all six years was 1.28 stalks (0.28 tillers) in the thick spacing and 2.39 stalks (1.39 tillers) in the thin spacing. The average ratio between the thick and thin spacings was 1.87 for stalks per plant and 4.96 for tillers. For the various groups the ratio of stalks per plant in the two spacings ranged from 1.32 in durra to 2.42 in sorgo.

Considerable differences are observed in tillering among varieties within a group, as might be expected. The Dwarf Yellow variety (C. I. 332) showed the highest average tillering capacity among the milos and Day was the lowest. In the kafir-milo group, Wheatland backcross was the highest and Smith milo×kafir was the lowest in tillering capacity. Wheatland showed appreciably higher tillering capacity than Beaver. Among the kafirs, Sunrise was high and Corneous was low. Another kafir showing high tillering capacity was Red kafir No. 7, which was selected from a Sunrise hybrid. Of the kafir-feterita derivatives, Club was high and Premo low. The feterita parentage of Club is merely assumed from plant characters, as the exact origin of this variety is not known.

Among the feteritas, Dwarf and Spur were distinctly low in the number of tillers per plant. All of the five durras tillered rather poorly and the "Pig-nose" variety developed almost no tillers, even in the thin spacing. The kaoliangs showed a wide range in tillering. The Blackhull variety, highest in the group, had an excessive average spacing of 42 inches. It also has certain characteristics which indicate that it might have become crossed with a feterita at some time before seed was sent to Woodward in 1914. All of the sorgos tillered freely except Leoti and the Cron strain of Orange.

Among the miscellaneous varieties, darso had few tillers, shallu had many, and Grohoma was slightly above the average for all varieties.

The tillering of the 105 varieties listed in Table 1 is shown graphically in Fig. 2, with the varieties arrayed in the order of the average number of stalks per plant in the thin (36-inch) spacing. "Pig-nose" durra shows the least tillering tendency and White feterita (C. I. 755) the greatest. In the lower two-fifths of the varieties in which the thin spacing produced not more than 2.00 stalks per plant and the thick spacing, with two exceptions, 1.20 stalks or less, will be found all of the durras, all but five of the kafirs, and most of the kaoliang varieties. Those that tiller freely, found in the upper fourth of the

varieties, produced 3 or more stalks per plant in the thin spacing and, with six exceptions, 1.40 or more stalks per plant in the thick spacing.

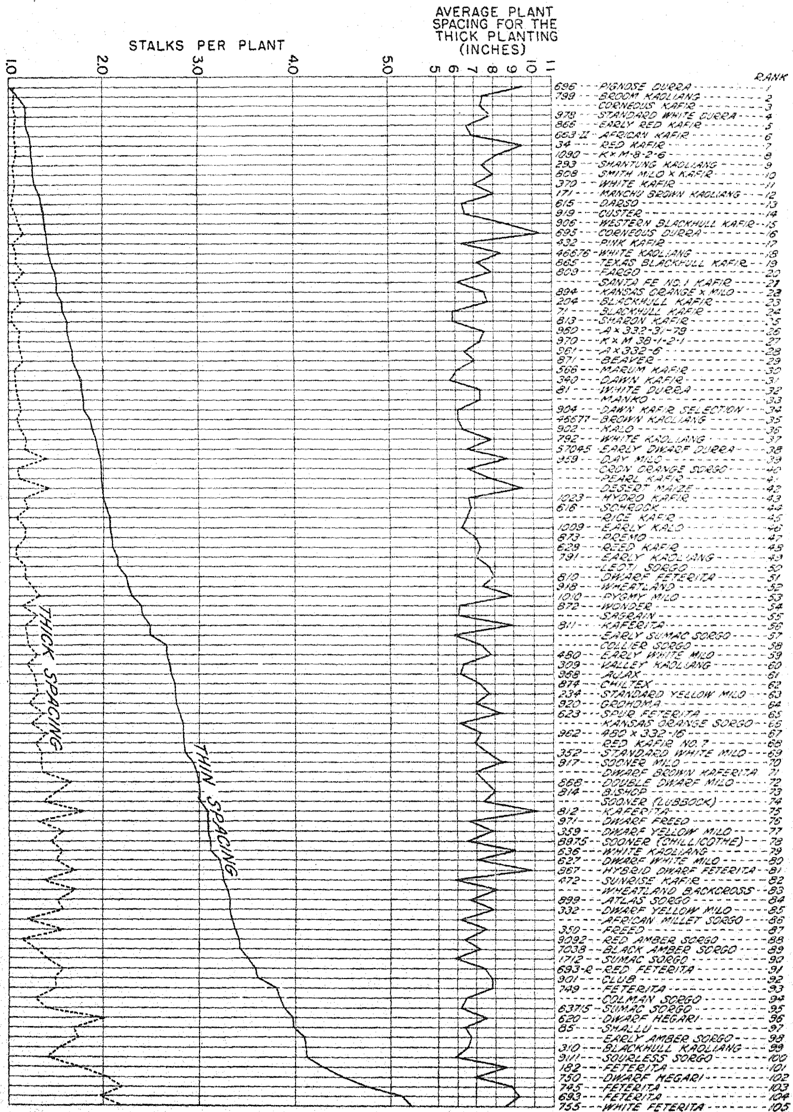

FIG. 2.—Average number of stalks per plant in thick and thin spacing of 105 sorghum varieties.

This high class contains both strains of hegari, all but 2 feteritas, 9 of the 14 sorgos, and 5 of the 13 milos. In the intermediate class are found Standard Yellow milo, Standard White milo, Early White

milo, Double Dwarf Yellow milo, and 5 of the 6 milo varieties that originated from crosses between Early White milo and Dwarf or Double Dwarf Yellow milo, *viz.*, Pygmy (C. I. 962), and the two strains of Sooner. Day milo produced slightly less than 2 stalks per plant.

Varieties of about average tillering ability include Wheatland, Sagrain, and kaferita (C. I. 811).

The number of stalks per plant, in general, follows the same varietal trends for the two spacings (Fig. 2), although varietal differences are smaller in the thick spacing. Exceptions to this trend are due largely to variations in the thick spacing above or below the average of 7.4 inches, as shown in Fig. 2. In the thick spacing a range of 4 inches in spacing, as would be expected, is much more important in tiller development than the same range in the thin spacing.

Hegari appears to differ from feterita in its tendency for tillering in thick spacing since it produced 2.03 stalks per plant in the thick spacing in which its average spacing was only 7.2 inches; whereas the feterita group produced only 1.76 stalks per plant with an average spacing of 8.5 inches. Both varieties of hegari are noticeably high in tillering in the thick spacing, as shown in Fig. 2, despite the fact that the actual spacing was about average for all the sorghums.

"Pig-nose" durra produced 1.05 stalks per plant in the thick spacing and only 1.02 stalks per plant in the thin spacing; tillering in this variety apparently was not affected by variations in spacing. Other varieties of low tillering capacity, as measured by the number of stalks per plant in the thin spacing, were affected only slightly by variations from the mean spacing of all varieties in the thick spacing. Varieties with a higher tillering capacity show a distinct response to variations from the 7.4-inch spacing.

DISCUSSION

The actual merits of tillering in sorghum production are difficult to evaluate, although it has been shown (2) that under favorable conditions tillers produce more than enough grain and stover to offset the decreased growth of the main stalk. The durras appear to be definitely limited in grain yield, even under favorable conditions, and the limited tillering may be largely responsible. Darso and Blackhull kafir show little tendency to tiller, but these varieties are among the most productive of grain in average seasons in the central and eastern portions of Kansas, Oklahoma, and Texas. It would appear that these varieties, with the stands ordinarily obtained, have sufficient stalks to develop as much grain as other factors affecting yields usually permit. Variations in head size in response to environmental differences help maintain the yields of these varieties. Their resistance to chinch-bug injury also is an important factor tending to favor them over other varieties with higher potential yields in the sections above mentioned.

Reed kafir, which tillered rather poorly in earlier plat experiments (7) but yielded best when the plants were about 6 inches apart, has ranked at or near the top in grain yield among the sorghums tested

at several western field stations in Oklahoma, Texas, and New Mexico. The exact reasons for this are not now ascertainable, but the ability of the Reed variety to tiller well in comparison with other kafirs when stands are thin may furnish a partial explanation. Irregularities in stand thus would be partly compensated for by the development of tillers in the Reed variety.

Sunrise and Dawn kafir offer an interesting comparison. These two varieties were selected from a single headrow grown from an early-maturing plant of kafir. Sunrise usually is about 1½ feet taller than Dawn and tillers much more freely, but otherwise the varieties are nearly identical. Sunrise, in general, produces about as much grain and considerably more stover than Dawn. As a rule, taller stalks and additional stover are associated with a corresponding reduction in grain yield as compared with other varieties having similar plant characteristics and the same length of growing period. It seems reasonable to assume that the additional tillers produced by Sunrise account for the grain yields nearly equal to those of Dawn, despite the higher production of stover in Sunrise. The similarity of Sunrise kafir and several sorgos in tillering behavior furnishes additional evidence that the strain of kafir from which it was selected may have been a segregate from a natural hybrid between a kafir and a sorgo.

Club, which was selected from Dawn kafir, but which probably was derived originally from a natural hybrid between kafir and feterita, has a tillering capacity very similar to that of feterita. The superior grain yields of Club in the Great Plains region, as compared with those of kafirs, possibly may be the result of better tillering ability.

Hegari has long been observed to tiller rather heavily despite unfavorable environmental conditions. This tendency to produce tillers regardless of spacing or season is shown in Table 1. Tillers on hegari plants usually develop during early stages. Hegari produces high yields of grain in a suitable temperature environment when ample moisture is present, but under dry conditions the excessive tillers apparently exhaust the available moisture supply and little or no grain is produced.

Dwarf Yellow milo usually tillers heavily, but the tillers often develop later than the main stalk and then largely in response to favorable environment. This tillering response largely accounts for the extreme adaptability of milo to varying spacing and moisture conditions. Milo under irrigation has produced the highest grain yields of any grain sorghum recorded in this country. Grain yields of 120 to 180 bushels per acre cannot be attained without considerable tillering when the plants are grown in rows 3 feet or more apart. Milo also is the outstanding sorghum for grain in the dry southwestern portion of the Great Plains area. There tillering in milo is limited when conditions are unfavorable and the plants usually produce a small crop of grain in severe seasons. The crop shows a strong response, however, to any additional moisture that is made available from summer fallowing or other practices supplying extra moisture. Of more importance, perhaps, than this moisture response is the ability of milo to tiller freely in order to compensate for additional space per plant

(4, 5, 10). Irregular stands of milo are not particularly detrimental to yield. Recent experiments under average Great Plains conditions have shown that milo yields vary only slightly when plant spacing within the row ranges from 6 inches to 6 feet. Such uniformity of yields can be attained only in a variety in which tiller development is sensitive to environment.

It is significant that varieties such as milo and hegari having a capacity for high grain yields of 75 bushels per acre or more under very favorable conditions also have a relatively high tillering ability. The heavy tillering of feterita and medium tillering of certain varieties of kaoliang, although probably favorable to high grain yields, cannot overcome the handicap of early maturity, slender, sparsely-leaved stalks, and frequent small heads, as compared with the higher yielding varieties of milo and hegari. Varieties having high potential grain yields such as Ajax and Grohoma are only slightly above average in tillering ability, but heavy heads and stalks and a long growing period make these varieties superior to feterita under favorable growing conditions.

Thick- and thin-spacing experiments reveal certain plant responses in addition to tillering. White durra (C. I. 81) was distributed because of its erect panicles, whereas the original White durra variety from which this strain was selected has recurved or "gooseneck" heads. The selected strain in ordinary field plat experiments and in the thick spacing in these experiments has always produced erect heads. In the thin spacing, however, during several seasons the heads of this variety were so thick and heavy when they emerged from the sheath that they were all recurved.

Another striking response in the spacing experiments has been the variation in the height of the plants. In ordinary seasons plant competition (probably for light) caused the stalks in the thick spacing to be appreciably taller than in the thin spacing. In dry seasons, however, the height relationship was reversed because the competition for moisture in the thick spacing was so severe that it caused stunting.

Thin spacing, as might be expected, encouraged the development of nodal branches on the sorghum stalks.

The chief value of these tillering data are in serving as a guide for the proper spacing of varieties. Results previously cited (4, 5, 7, 10) suggest that varieties which tiller poorly should be planted relatively thick for maximum grain yields, usually about 6 inches apart, except under very dry conditions. Feterita plants apparently should be spaced about 12 inches apart. Milos, depending upon the tillering ability of the varieties, adapt themselves to a wide range of spacing. Recent experiments have shown that Beaver requires thicker spacing than the related variety, Wheatland, which produces more tillers. All varieties, however, produce the highest yields of forage when planted thick.

SUMMARY

The number of stalks per plant in 105 varieties of sorghum grown at Woodward, Okla., from 1930 to 1937 was determined in rows in

which the plants were spaced at two distances, *viz.*, about 7 inches and 36 inches apart.

In stalks produced per plant in the 36-inch spacing, the various sorghum groups ranked from the greatest to the least number as follows: Hegari, feterita, sorgo, milo, kaoliang, kafir, and durra. The six-year average number of stalks per plant in 79 varieties was 1.28 in the 7-inch spacing and 2.39 in the 36-inch spacing. Some varieties produced no tillers in certain seasons, but one variety produced an average of 6.8 stalks per plant in the 36-inch spacing in 1936.

The rank of the varieties in number of stalks per plant was very similar in the two spacings, except when spacing was not uniform, although varietal differences were smaller in the 7-inch spacing than in the 36-inch spacing. Small variations from the average spacing had little effect on the number of stalks per plant in the kafirs and other varieties that produced few tillers but such variations were important in many varieties that tiller freely.

Hegari produced a considerable number of tillers in all seasons and in both spacings. Dwarf Yellow and certain other varieties of milo usually tillered freely, but tillering fluctuated more with environment than in hegari.

Differences in tillering appear to account for many of the yield relationships and adaptations that have been observed in sorghum varieties. The proper plant spacing for a variety depends largely upon its tillering ability. Varieties that tiller poorly should be planted relatively thick.

LITERATURE CITED

1. Ball, C. R., and Rothgeb, B. E. Grain sorghum experiments in the Panhandle of Texas. U. S. D. A. Bul. 698. 1918.
2. Bartel, A. T., Martin, J. H., and Hawkins, R. S. Effect of tillers on the development of grain sorghums. Jour. Amer. Soc. Agron., 27:707–714. 1935.
3. Hastings, S. H. The importance of thick seeding in the production of milo in the San Antonio region. U. S. D. A. Bul. 188. 1915.
4. Karper, R. E. The contrast in response of kafir and milo to variations in spacing. Jour. Amer. Soc. Agron., 21:344–354. 1929.
5. ———, Quinby, J. R., Jones, D. L., and Dickson, R. E. Grain sorghum date-of-planting and spacing experiments. Tex. Agr. Exp. Sta. Bul. 424. 1931.
6. ———, ———, ———, ———. Grain sorghum varieties in Texas. Tex. Agr. Exp. Sta. Bul. 459. 1932.
7. Martin, J. H., Sieglinger, J. B., Swanson, A. F., Burnham, D. R., Clemmer, H. J., Coles, E. H., Keating, F. E., and Osborn, W. M. Spacing and date-of-seeding experiments with grain sorghums. U. S. D. A. Tech. Bul. 131. 1929.
8. Quinby, J. R., Stephens, J. C., Karper, R. E., and Jones, D. L. Forage sorghums in Texas. Tex. Agr. Exp. Sta. Bul. 496. 1934.
9. Sieglinger, J. B. Grain sorghum experiments at the Woodward Field Station in Oklahoma. U. S. D. A. Bul. 1175. 1923.
10. ———. The spacing of grain sorghums. Jour. Amer. Soc. Agron., 18:525. 1926.

EFFECT OF ARTIFICIAL DRYING UPON THE GERMINATION OF SEED CORN[1]

T. A. Kiesselbach[2]

THE artificial drying of ear corn with heated air under forced draft is coming into rather common usage by extensive growers of hybrid seed. Under good management, this practice may remove the hazards of freezing injury, and it facilitates early harvest, storage, and processing. There are no indications that hybrid seed is in more need of artificial drying than is seed from open-pollinated varieties, but its greater value has made growers more cautious. For recent evidence of widepsread, serious freezing injury to seed corn one need but recall the year 1935 when the crop in most of the corn belt was subjected to late maturity and severe early frost. As shown in an earlier paper,[3] there is a very definite inverse relationship between the moisture content of the seed and the degree and duration of freezing temperature that it will withstand without loss of viability.

Because of the comparative newness of the practice and the inexperience of operators in commercial production, seed injury sometimes results during the drying process because of faulty manipulation. Questions frequently arise regarding suitable temperatures, length of drying, moisture relations, and reaction of different hybrids. It is the chief object of this paper to report the results of a number of tests made at the Nebraska Agricultural Experiment Station in 1937 and 1938 which bear on these problems.

DRYING EQUIPMENT

The procedure was fairly similar to that reported by Harrison and Wright[4] of the Wisconsin Experiment Station. A series of four 4 x 6 x 9 feet drying bins, installed in the Agronomy Laboratory Building, have been used with satisfaction during the past six years. With some modifications, these are patterned after those described by Wright and Duffee[5] and operate according to the same principles. The bins have a temperature range of 100° to 220° F and may be kept constant within 3° variation by thermostatic control.[6]

The air is heated by blowing over a high-pressure steam radiator by means of a fan driven by a variable speed 3-horse electric motor which delivers 2,840 cubic

[1]Contribution from the Agronomy Department, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Authorized for publication by the Director as Journal Article No. 228 of the Nebraska Agricultural Experiment Station. Received for publication February 3, 1939.

[2]Agronomist.

[3]Kiesselbach, T. A., and Ratcliff, J. A. Freezing injury of seed corn. Nebr. Agr. Exp. Sta. Res. Bul. 16. 1920.

[4]Harrison, C. M., and Wright, A. H. Seed corn drying experiments. Jour. Amer. Soc. Agron., 21:994–1000. 1929.

[5]Wright, A. H., and Duffee, F. W. The bin method of drying seed corn. Mimeographed circular from the Departments of Agronomy and Agricultural Engineering, Wisconsin College of Agriculture. 1929.

[6]Although only the lower temperature range is needed for drying seed, the higher heat capacity was provided for use in connection with yield tests to reduce representative samples of grain and forage to a comparable and essentially moisture-free condition.

feet of air per minute at 900 r.p.m. and 5,700 cubic feet at 1800 r.p.m. The combined volume of the four bins is 864 cubic feet. For economy, the heated air is partially used over again, some fresh air being continually introduced. At 12-hour intervals, the direction of the air is reversed to enter the bins alternately from above and below.

For the various tests herein described the initial bin temperature was brought to the desired degree and continued constant. The actual temperatures and length of drying intervals are given in the tables.

TESTING FOR GERMINATION

Soon after the drying was completed, germination tests were run at 85° F by the rag-doll method. Each lot of ears was tested in duplicate, using 200 kernels picked at random in equal numbers from each ear. The kernels were classed as germinated if both plumule and root grew. Comparative germination vigor was noted.

RESULTS

EFFECTS OF INITIAL MOISTURE, TEMPERATURE, AND DURATION OF DRYING

Moisture variations of corn tested.—In 1937 mature ear corn of the Krug variety was harvested from the field on September 16 and immediately divided on the basis of appearance and feel into three groups representing low, medium, and high moisture content. The mean moisture contents in the grain of these respective groups were 19, 27, and 30%. A similar harvest and grouping of ears was made on September 22 when the respective moistures were 13, 19, and 23%. The drying tests were started on the day of harvest as soon as the ears were classified. No killing frosts had occurred at the time of gathering the corn from the field.

In the fall of 1938, two similar harvests were made on September 14 and September 20, for the purpose of studying the effect of higher moisture contents than those of 1937. The ears picked on each date were divided into two groups averaging 50 and 57% moisture on September 14 and 49 and 56% moisture on September 20.

Temperature and duration of the drying period.—Recommended seed-drying temperatures have come to be fairly well standardized at between 105° and 110° F. In these experiments, the ears picked at the first harvest each year were dried at 112° F, while those of the second harvest were dried at 107° F. Such procedure was necessary because only one temperature could be maintained at a time by the equipment available.

The ears of each moisture group were randomly divided into several lots of 20 ears each for drying at varying intervals. There were 11 such lots of the low moisture group in 1937 and 6 lots of all other groups each year.

One lot of each group dried naturally at room temperature, approximately 70° F. All other lots in each test were placed in the drying bin simultaneously but were withdrawn successively at 24-hour intervals. Moisture determinations of representative grain samples were made for each lot in 1937 at the close of their drying periods.

Results.—The data obtained in 1937 and 1938 are reported in Tables 1 and 2, respectively. At 112° F there were no significant effects on the percentage or vigor of germination for seed averaging 19, 27, and 30% moisture. Even after 5 days of drying, when the seed had reached a moisture content of about 5%, these moisture groups gave the respective germinations of 97.5, 99.5, and 99.5%. Subjected to slow natural drying, their germinations were 98.5, 99.0, and 99.5%. When the grain contained as high as 50 and 57% moisture at time of placing in the drying bin, the germination rather gradually fell off in five days to 90.5 and 83%, respectively. The vigor of sprouts was also greatly reduced at these high moisture contents.

At 107° F there also were no significant effects on either the percentage or vigor of germination for the three lowest moisture groups containing 13, 19, and 23% moisture, respectively. After five days of drying when the moisture had been reduced to about 6.5%, the respective germinations were 98.1, 97.9, and 97.0%. Corresponding naturally dried samples germinated 98, 97, and 98%. When the grain contained 49 and 55% moisture as husked, the respective germinations were 97.5 and 82%. At 49% initial moisture, the seed satisfactorily withstood drying at 107° F and gave strong, vigorous sprouts at all drying intervals. At the higher initial moisture, 55%, however, the vigor of the sprouts as well as the percentage germination were materially reduced.

Ear corn subjected to the non-harmful temperature of 107° F for as long as 35 days reached a moisture content of 4.3% and had not fluctuated more than 0.2% during the preceding 28 days. At the end of this period the seed germinated 98% or the same as the naturally dried seed.

DIFFERENTIAL RESPONSE OF HYBRIDS

In order to get some indication as to whether there are important heritable differences in the response of corn to artificial drying, 26 comparably grown single crosses were dried for a period of 5 days at 112° F. This relatively high temperature was used since it might be expected to be more selective of heat-susceptible hybrids than a lower temperature.

Five mature ears of each hybrid were picked on September 14. Their mean moisture contents before drying and their percentages of germination after drying are reported in Table 3. There was considerable moisture variation because of difference in time of maturity. The extreme range of germination was 96 to 100%, while only one hybrid fell under 97.5%. These data indicate no important differential response for the different hybrids. Under conditions of commercial production the seed would not be subjected to so long a drying period and there would be even less likelihood of injury than in these experiments. There is of course a possibility of differential response at temperatures higher than that here employed, but higher temperatures are regarded as hazardous and are not recommended.

Were such a collection of hybrids harvested under conditions of higher mean moisture content, ranging perhaps between 35 and 60%, it is possible that variable injury from artificial drying would be

TABLE 1.—*Effects of artificially drying ear corn differing in moisture content at 112° and 107° F for various intervals under forced draft upon the drying rate and viability of the seed, 1937.*

Classification of ear corn as to moisture content	Percentage moisture in grain						Percentage germination* of seed after						
	When harvested	After artificial drying					Natural drying	Artificial drying					
		1 day	2 days	3 days	4 days	5 days		1 day	2 days	3 days	4 days	5 days	Av.
Drying Temperature 112° F (Test Begun Sept. 16)													
Low	19.0	9.3	6.0	5.0	5.1	5.0	99	100	100	99	99	98	99
Medium	27.0	12.5	9.4	6.0	5.0	5.0	99	100	100	100	100	100	100
High	30.1	15.2	12.0	6.5	5.0	5.4	100	99	100	98	99	100	99
Average	25.4	12.3	9.1	5.8	5.0	5.1	99	100	100	99	99	99	99
Drying Temperature 107° F (Test Begun Sept. 22)													
Low†	13.0	8.2	6.2	6.6	6.6	5.8	98	98	98	99	99	98	98
Medium	19.4	11.8	9.2	6.2	6.8	6.6	97	97	97	98	100	98	98
High	23.4	14.8	10.0	7.0	6.4	6.5	98	94	97	100	98	97	97
Average	18.6	11.6	8.5	6.6	6.6	6.3	98	96	97	99	99	98	98

*No differences were noted in the vigor of germination.

†Corresponding samples with initial low moisture content were continued at the temperature of 107° F for the periods of 6, 7, 8, 9, 10, and 35 days. At these prolonged intervals of drying, the respective moisture contents of the grain were 5.4, 5.5, 5.0, 5.2, 5.0, and 4.3%, while corresponding germinations were 98.0, 98.0, 97.5, 96.5, 98.5, and 98.0%.

TABLE 2.—*Effects of artificially drying ear corn of high moisture content at 112° and 107° F for various intervals under forced draft upon the viability of the seed, 1938.*

Classification of ear corn as to moisture content	Moisture in grain when harvested, %	Germination after natural drying, %	Percentage germination of seed after artificial drying					Percentage vigor* of germination after artificial drying					
			1 day	2 days	3 days	4 days	5 days	0 day	1 day	2 days	3 days	4 days	5 days
Drying Temperature 112° F (Test Begun Sept. 14)													
Very high	49.9	97.0	96.5	92.0	93.5	90.0	90.5	95	92	80	85	78	78
Extra high	57.1	97.5	93.5	89.0	89.5	84.0	83.0	93	80	75	73	72	73
Average	—	97.3	95.0	90.5	91.5	87.0	86.8	94	86	78	79	75	75
Drying Temperature 107° F (Test Begun Sept. 20)													
Very high	49.2	98.5	98.0	99.0	98.5	97.0	97.5	95	95	95	95	93	95
Extra high	55.4	96.0	92.5	89.5	85.5	85.0	82.0	95	90	85	75	77	75
Average	—	97.3	95.3	94.3	92.0	91.0	89.8	95	93	90	85	85	85

*The vigor of germination is based on an arbitrary scale ranging between 70 and 95%, in which 70 signifies decided inferiority and only about one-half as much sprout growth as 95.

apparent. This would seem due, however, to difference in moisture content rather than heritable susceptibility.

TABLE 3.—*Effect of artificially drying mature ear corn of 26 single-cross hybrids for five days under forced draft at 112° F upon the viability of the seed, 1938.**

Hybrid	Moisture content of ear corn, %	Germination, %	Hybrid	Moisture content of ear corn, %	Germination, %
K×1628×K 1605	34.3	99.0	WR 1999×K 1558	26.0	99.5
I 420×A	24.1	97.5	I 234×K 1620	19.3	98.0
I 205×L 289	22.3	99.5	N6×K 1620	33.3	99.0
GR 87×L	37.8	97.5	K 1619×WR 1999	31.3	99.5
Os 426×I 197	18.8	99.0	RR 1756×2144	16.1	100.0
R4×GR 100	19.7	99.5	N6×L 317	36.6	98.5
K 1637×HG 7487	30.2	100.0	I 205×K 1620	29.4	100.0
Os 420×K 1616	29.8	96.0	WR 1916×BuR 1768	21.1	100.0
I 197×GR 87	29.2	99.5	Os 420×Os 426	27.2	100.0
K 1650×2083	31.6	99.0	R4×L 317	27.3	99.0
R4×GR 87	28.5	99.0	I 234×L 289	16.7	100.0
Hy×CC 1862	26.3	99.5	L 289×N6	24.1	99.5
K 1562×WR 1916	20.8	99.0	K 1515×BuR 1829	20.0	99.0

*No differences were noted in the vigor of germination, all being satisfactory.

MOISTURE ABSORPTION BY SEED AFTER EXCESSIVE DRYING

For the purpose of studying the rapidity of atmospheric moisture absorption after excessive drying, bulk samples of both ear and shelled corn containing 6% moisture were exposed in burlap bags for 12 days in the seed room at about 70° F and thereafter for 12 days in an open, unheated shelter. During the first 12-day interval, the moisture content of the ear and shelled corn rose respectively to 7.3 and 7.4%. At the end of the second 12-day period the respective moisture contents had risen to 9.0 and 10.7%, the latter being a close approach to an air-dry equilibrium under the conditions.

DISCUSSION

The objectives of artificially drying seed corn are attained as soon as the seed is reduced to a moisture content safe from storage and freezing injury. Drying beyond such point would be needless expense. It has been ascertained that seed containing not to exceed 14% moisture will withstand any degree of cold and may be stored without loss of quality or viability. For commercial seed production, drying to a mean moisture content of 12 to 13% is recommended. Drying of the bulk seed slightly below the upper limit of tolerance will tend to insure against some of the kernels being insufficiently dried.

To illustrate, the grain of a bulk sample of Krug ear corn averaged 25% moisture when husked. When the ears were sorted into three equal groups according to apparent moisture content, the three lots contained 19, 27, and 30% moisture, respectively. After artificial drying at 112° F for 24 hours the mean moisture content had been reduced to 12.3%, but that of the three separate lots was 9.3, 12.5,

and 15.2%. In another but similar case, the bulk ears contained 18% moisture, whereas separation according to apparent moisture gave three equal groups with 13, 19, and 23% moisture. At the end of 24 hours drying at 107° F, the mean moisture had reduced to 11.6%, while the three respective lots contained 8.2, 11.8, and 14.8% moisture. If ears of varying moisture content were mixed together in large quantity as in bulk commercial drying, there would doubtless be a greater tendency toward equalization in the drying rate of the component ears.

In commercial practice, the moisture content of representative grain should be determined at intervals during the drying process by a Duvel oil tester or other satisfactory rapid means, and the heating should be discontinued when the desired moisture content is attained. For corn containing 20% moisture, about one day of drying should suffice, while two days should be ample when the moisture content is 30%. Three days may be needed when there is 50% moisture. The ears should be husked clean as the presence of many husks interferes with air circulation and retards drying. Underdrying may cause inconvenience through loss in weight during storage after the seed has been weighed into bushel bags. Likewise weighed bags of seed corn that has been dried excessively will gradually absorb atmospheric moisture and gain in weight until an equilibrium is reached.

In the Nebraska Agricultural Experiment Station seed-corn-drying tests, the percentage and vigor of seed germination were uninjured by artificial drying at a temperature range of 107 to 112° F when the initial moisture content of the grain did not exceed 38%. This was true even though the duration of artificial drying and the degree of desiccation materially exceeded that needed and recommended in commercial practice. However, when the moisture reached 50%, the germination was materially reduced by prolonged drying at 112° F, and with 55% or more moisture it was seriously reduced. On the other hand, at a somewhat lower temperature, 107° F, seed with 49% moisture was unaffected, while seed with 55% moisture was seriously injured.

Although immature corn with excessively high moisture content has not been extensively studied, there appears to be an inverse relation between moisture content and high-temperature tolerance. This corresponds with the previously established principle applying to the freezing injury of seed corn, in which there is an inverse relation between moisture content and low temperature tolerance.

Fully matured seed corn of reasonably low moisture content may be artificially dried at 107° to 112° F without unfavorably affecting the appearance of the seed as to color, lustre, and wrinkling of pericarp.

A field yield test of all the seed lots dried artificially in 1937 failed because of the severe drouth. Observations of field stand and seedling growth, however, disclosed no differences in relation to moisture content of the seed or to duration and degree of high temperature. The seed used in these field plantings did not exceed 30% moisture when placed in the drier and the temperature did not exceed 112° F.

All commercial and experimental lots of hybrid seed produced at the Nebraska Experiment Station have been artificially dried at 105°

to 110° F during the last five years. No ill effects from such treatment have been observed when the seed was planted in the field.

In general, these results agree with those of Harrison and Wright who found at the Wisconsin Agricultural Experiment Station that seed corn was uninjured as to germination, seedling growth, and field performance by drying in the ear to as low as 4% moisture content under forced draft at the non-harmful temperatures of 104° to 113° F. These Nebraska data would merely tend to lower the upper temperature limit in the case of corn with unusually high moisture content.

SUMMARY

The timely artificial drying of seed corn with heated air under forced draft may remove the hazard of freezing injury and facilitate early harvest, storage, and processing. If suitable procedure is followed, no injury results to viability or field performance of the seed.

In connection with such artificial drying, a reduction in the moisture content of the seed to 12 to 13% at a temperature range of 105° to 110° F is recommended except that the temperature be held as low as 105° F when the initial moisture content approaches 50%.

Prolonged drying at safe temperatures to a moisture content as low as 5% is not harmful to the seed. Such thorough desiccation is impractical, however, as it involves needless expense and time and causes inconvenience when bagged for storage in weighed quantities by gradual increase in weight through absorption of atmospheric moisture. Likewise, insufficient drying subjects the seed to later loss of weight and possible deterioration during storage. The permissible range of moisture content for safe processing and storage approximates 5 to 14%.

The length of drying interval needed to reduce ear corn to a safe moisture content varies with the initial moisture content of the grain and the drying temperature. Such duration may approximate 1, 2, or 3 days for corn containing 20, 30, and 50% moisture, respectively, provided the air is sufficiently changed.

There appears to be an inverse relation between drying temperature and minimum moisture content attained by the dried seed. After five days of drying at a temperature of 112° F, the moisture approximated 5% while at 107° F it was about 6.5%. It appears that little further desiccation would occur from prolonged exposure at these temperatures. A lot of seed ears dried for 35 days at 107° F contained 4.3% moisture and germinated 98%.

Seed with an initial moisture content up to 30% and reduced to as low as 5% by artificial drying for 5 days at 112° F showed no unfavorable stand or seedling growth effects when planted in the field.

At a drying temperature of 112° F no significant differential injury was found among 26 representative hybrids ranging in moisture content from 16 to 38%. It would seem possible that among hybrids differing greatly in moisture content at the time of drying, those with excessive moisture would be injured. This would not necessarily suggest heritable difference in heat susceptibility, and might be associated solely with moisture content.

THE CARBOHYDRATE-NITROGEN RELATION IN LEGUME SYMBIOSIS[1]

P. W. WILSON AND E. B. FRED[2]

IN a recent issue of this JOURNAL, Allison and Ludwig (2)[3] make a strong plea for retention of their version of the carbohydrate supply hypothesis originally proposed by Mazé (8) and subsequently amended and developed by other workers (5, 7, 10, 12). The ingenious summation of the hypothesis made by Allison (1) possesses an apparent simplicity which recommends it to the consideration of students in this field of research. Nevertheless, the extensive experiments carried out by the authors and their colleagues, together with data from other stations, have led us to the conclusion that the carbohydrate supply hypothesis is inadequate for many aspects of legume symbiosis. Its recent defense contains no new material which would lead to alteration of that conclusion.

At the same time that the views based on the importance of the carbohydrate supply were being developed, rival theories appeared which ascribed the dominant rôle to the nitrogen supply—both inorganic and organic (4, 6, 11). The chief difficulty with both proposals was lack of critical data and especially data from different types of experiments. Almost all of the pertinent tests had dealt with a single method of changing the carbohydrate and nitrogen supply, *viz.*, by addition of combined nitrogen to inoculated leguminous plants. From such experiments it is impossible to separate the effects due to depletion of the carbohydrate from those due to presence of increased nitrogen.

In 1930 research was begun at the Wisconsin Experiment Station which determined the response of several functions of the symbiotic nitrogen fixation system to changes in the supply of carbohydrate and/or nitrogen induced by means other than addition of combined nitrogen. It was only when such data became available that critical examination of the various theories could be undertaken. As a result of this examination it was concluded that both points of view were too limited and circumscribed in their outlook. As is frequently the case, both theories were satisfactory in certain areas of the field, but neither completely sufficed. It appeared that a hypothesis which would take into account the rôle of both carbohydrate and nitrogen would be more satisfactory.

It should be noted that at no time did we favor the carbohydrate supply hypothesis and later abandon it for one based on the relation[4]

[1]Herman Frasch Foundation in Agricultural Chemistry, Paper No. 192, Department of Agricultural Bacteriology, University of Wisconsin, Madison, Wis. Received for publication April 24, 1939.

[2]Associate Professor and Professor of Agricultural Bacteriology, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 502.

[4]On the advice of several authorities who are interested in the subject from the point of view of plant physiology we have used the term, *relation*, in general discussion. They point out that it is incorrect to speak of ratios unless a definite ratio is meant; hence, the term carbohydrate-nitrogen ratio is restricted to discussion of specific data and then only when the particular ratio is defined. Also, use of the term, *relation*, should prevent confusion with any particular mechanism associated with a "carbohydrate-nitrogen ratio" theory.

between carbohydrate and nitrogen in the host plant as is suggested by Ludwig and Allison. In our initial publication (3) our position was thus stated,

"The present paper is concerned with the carbohydrate-nitrogen relation of inoculated leguminous plants, especially as affected by the gaseous environment of the plant and the influence of this relation on nodule formation and nitrogen fixation. The data show a definite correlation between the nitrogen-fixing, photosynthetic and respiratory functions in leguminous plants and afford a common basis for interpretation of problems relating to the following aspects of the fixation process: (a) quantity of nitrogen fixed; (b) size, number and distribution of nodules; (c) effect of combined nitrogen on fixation of free nitrogen."

The essential features and interpretations of the hypothesis, which the following summary shows are neither vague nor complicated, were incorrectly given in the article by Allison and Ludwig. For this reason explicit statement of these will be furnished:

1. Various responses of the symbiotic nitrogen fixation system are regarded as functions of both carbohydrate and nitrogen supply as measured by the relation between them. The particular measure to be used will be discussed later in this paper.
2. If the relation between carbohydrate and nitrogen is such that the supply of the former is the limiting factor, any change in this supply will be reflected in the responses of the fixation system; similarly, with the supply of nitrogen. For example, *invasion of the plant*, as measured by number of nodules, ordinarily is quite responsive to changes in the carbohydrate level as this is the limiting factor. On the other hand, if inoculation of the plants is delayed so that an excess of carbohydrate accumulates, the limiting factor for *development of the nodules* is the supply of nitrogen. Under such circumstances this function of the symbiotic system will be stimulated through addition of combined nitrogen.
3. Even though one of the factors under specified conditions dominates a given response through being the limiting factor, the rôle of the other should not be overlooked. The carbohydrate-nitrogen relation hypothesis regards *at all times* the responses of the symbiotic system as dependent on both carbohydrate and nitrogen supply and thus avoids treating the two cited examples as distinct phenomena with different "causes". In this way the hypothesis provides a consistent, unified, and economical explanation which embraces many different responses of the symbiotic system.

It is emphasized that there is no compulsion about using a carbohydrate-nitrogen ratio as the measure of the relative supply of carbohydrate and nitrogen. Any function of the two which would involve their simultaneous consideration and which could be *conveniently determined* should be equally satisfactory. Because of the use of the ratios in certain fields of both soil microbiology and plant physiology, they appeared to be the logical measures to adopt. Especially to be avoided are interpretations that the relation operates in a mystical

manner. The relation (or specific ratios in actual cases) serves only as a convenient measure of carbohydrate and nitrogen supply; the *mechanism* of its operation is primarily how these affect the plant's functions. For many years soil microbiologists have used the C:N ratio as a convenient indicator of the type of decomposition to be expected, but no one has ever seriously proposed that the term means anything more than the relative supply of energy and structural materials.[5] Certain plant physiologists may have attempted to attribute to the ratios a regulatory influence beyond that of the chemical function of each component, but the view has never met with great approval (9).

Methods for estimation of the relation were discussed and applied to actual cases by Wilson (13). The same ratio could not be expected to be equally satisfactory for all responses since the forms of nitrogen and carbohydrate which are most directly concerned probably vary. The ultimate goal of the biochemical studies is to define exactly the nature of these, but to reach that goal will require much research and likely a better comprehension of general plant metabolism than is now available. In the meantime, it is of interest to determine if valuable correlations can be established between some crude measure of the actual causal factors and certain responses of the symbiotic nitrogen fixation system.

Such correlations were discussed by Wilson (13) who employed various ratios for measuring the carbohydrate-nitrogen relation, including total carbohydrate/total nitrogen, total carbohydrate/soluble nitrogen, soluble carbohydrate/total nitrogen, and soluble carbohydrate/soluble nitrogen. The use of different ratios was not the result of a haphazard selection but dictated by necessity—in most cases the choice of the measure was determined by the data available. However, the important fact is that for the broad, but nevertheless useful, generalizations which were drawn, any one of the measures appears to be sufficiently accurate. In the few cases in which comparisons were possible among two or more measures and some definite response, it appeared that, usually, the correlations were more obvious and consistent if total carbohydrate/soluble nitrogen was used, but this conclusion is tentative as the data for judgment are quite few. Unfortunately, the necessary chemical determinations which would allow calculation of any one of these ratios have been seldom made so that in the majority of the tests made on the theory the inverse ratio, total nitrogen/dry weight, or *per cent* N, was employed. Although this admittedly is a very crude measure of the factors believed to be responsible, it has the advantage that it is readily, and what is more important, usually is, estimated. In actual practice it has served very well, and until determination of the others become more common, it is likely that it will have to suffice. The chief objection which can be raised against this measure of the relation is that it is probably

[5]The similarity between the carbohydrate-nitrogen hypotheses in soil decompositions and legume symbiosis was the precise feature emphasized in the first extensive discussion of the hypothesis by the senior author. This presentation was made at the symposium on *Decomposition of Organic Matter in the Soil* held in connection with the 1934 meeting of the Society of American Bacteriologists.

only a rough estimate of the real causal factors. Hence, conclusions derived from the hypothesis probably should remain open to revision until more refined data are obtained.

It is evident that there is nothing intangible or vague about estimation of the Ch:N relation provided the trouble is taken to make the required chemical determinations. In this connection the equally important query should be raised, What is the appropriate measure of "carbohydrate supply"? Examination of the literature concerned with this hypothesis reveals that the effects are related to such ill-defined substances as "metabolizable carbon", "available carbohydrate", "carbohydrate delivered to the site of the nodules". No information is provided with reference to the estimation of these supposedly simple, but actually vague, concepts of carbohydrate supply, except that they do not correspond to mere determination of carbohydrate in the plant sap. Until specifications are laid down for determination of the regulatory factor—even if only in a crude manner—it is difficult either to test or to apply the hypothesis.

Consideration of the various terms used to indicate "carbohydrate supply" suggests that this hypothesis implicitly contains that based on the carbohydrate-nitrogen relation. As has been indicated, the important factor appears to be not total carbohydrate but "available carbohydrate", i.e., carbohydrate that can be used primarily for energy needs. "Available carbohydrate", then, will be primarily carbohydrate in excess of that required for structural purposes; the latter will depend on nitrogen supply. Hence, in order to obtain a measure of available carbohydrate, it is necessary to use some function which will include consideration of the "available nitrogen." It is suggested that a carbohydrate-nitrogen ratio (which usually can be measured by *per cent* N) is a suitable function to use.

Since Allison and Ludwig, and not ourselves, introduced the interpretation that the ratio as such is the causal agent, it is scarcely necessary to consider in detail the majority of their objections to the carbohydrate-nitrogen hypothesis.[6] In our opinion, the disagreement is largely pointless since it resolves itself into: How large a field is to be covered by a particular hypothesis? Invasion of the plant (number of nodules) is a function of the Ch:N relation in which the limiting factor is primarily supply of carbohydrate. It is not surprising then that the responses of this function can be satisfactorily accounted for entirely on the basis of the carbohydrate supply hypothesis, a fact that was emphasized by Allison and Ludwig who apparently wished to confine the discussion to development of nodules. With other functions, however, the primary attention is focused on the supply

[6]The statement of Allison and Ludwig regarding Wilson's misunderstanding of the top-root ratio hypothesis is in error as is clearly evident by consulting the original paper (13). In the experiments considered by Wilson, the top-root ratio was altered on plants by changes in the length of day, clipping of leaves, temperature, and intensity of light. There is just as much reason to believe that the factor altering the top-root ratio in these plants is the supply of carbohydrates to the roots as when addition of combined nitrogen is followed by a change in this ratio. Nevertheless, such alteration was accompanied by erratic responses with respect to development of nodules; hence, there seems to be no reason for changing the conclusion drawn in the bulletin.

of nitrogen. These include (a) breaking the nitrogen-hunger period, (b) use of strains of bacteria of low efficiency, (c) development of nodules and initiation of fixation in plants in which inoculation has been delayed, and (d) probably excretion of nitrogen in which excess nitrogen apparently accumulates from the symbiotic nitrogen-fixing system rather than from an external source. In order to consider these cases it is not necessary to shift from a hypothesis which stresses carbohydrate to one which emphasizes the supply of nitrogen. Although the plea might be made that these do not represent "normal" conditions and hence are not meant to be considered in application of the hypothesis, it must be emphasized that they are not infrequently encountered in actual practice. If a hypothesis is to be more than a mere intellectual diversion, it should certainly include consideration of these "exceptions". The Ch:N relation hypothesis, as well as Allison's original version (1) of the carbohydrate supply hypothesis, was offered as a comprehensive explanation of many phases of legume symbiosis and not merely to restricted areas of the field.

SUMMARY

In reply to the criticisms of Allison and Ludwig, advantages of the carbohydrate-nitrogen hypothesis over the carbohydrate supply hypothesis are discussed. These include:

1. It combines in a single hypothesis consideration of both supply of nitrogen and of carbohydrate and thus replaces both. It is pointed out that the carbohydrate supply hypothesis itself implies that the proper measure is the relation between carbohydrate and nitrogen rather than carbohydrate alone. A leguminous plant, by reason of the nitrogen fixation system in the nodules, exercises some internal control over its nitrogen supply independent of what the experimenter does with the external source of combined nitrogen. For this reason, it is believed that photosynthesis and nitrogen fixation must be considered as interrelated processes and that the function of one should not be emphasized at the expense of the other. In some cases the supply of carbohydrate is the dominant factor, but in others the reverse is true. When the supply of nitrogen rather than carbohydrate is the effective agent, interpretation in terms of carbohydrate supply becomes artificial.
2. The Ch:N relation has several definite measures of varying degrees of refinement, whereas the carbohydrate supply hypothesis has, in the past, employed such concepts as "available carbohydrate" and "metabolizable carbon" without specifying methods for their estimation. Moreover, even if the usual measures of carbohydrate supply, as *total* or *soluble* carbohydrate, are employed as a crude estimate of the "available carbohydrate", the determination is much less a routine operation with most workers than is the corresponding measure of Ch:N relation (*per cent* N). For this reason the hypothesis based on the relation can be more readily extended and applied to practice.

Our own experience has led us to the conclusion that it is an avoidable oversimplification to consider carbohydrate supply as the pri-

mary factor in legume symbiosis and to relegate the supply of nitrogen to a secondary rôle of serving as one method for control of carbohydrate. However, we do not consider the question of which hypothesis is "true" as a very critical one. The major requirement at this time for advancement in understanding of the biochemistry of legume symbiosis is experimental facts. If any hypothesis suggests means for obtaining these facts, its use will be justified irrespective of final judgment as to its validity. There are yet numerous questions to be answered relative to the importance of both nitrogen and carbohydrate in legume symbiosis; it is suggested that energy directed towards securing the much-needed quantitative data would be much more profitably expended than in fruitless controversy.

LITERATURE CITED

1. ALLISON, F. E. Carbohydrate supply as a primary factor in legume symbiosis. Soil Science 39:123–143. 1936.
2. ———— and LUDWIG, C. A. Legume nodule development in relation to available energy supply. Jour. Amer. Soc. Agron., 31:149–158. 1939.
3. FRED, E. B., and WILSON, P. W. On photosynthesis and free nitrogen assimilation by leguminous plants. Nat. Acad. Sci. Proc., 20:403–409. 1934.
4. GIÖBEL, G. Relation of soil nitrogen to nodule development and nitrogen fixation by certain legumes. N. J. Agr. Exp. Sta. Bul. 436. 1926.
5. HOPKINS, E. W., and FRED, E. B. Influence of various nitrogenous compounds and mannitol on nodule formation by clover. Plant Physiol., 8:141–155. 1933.
6. LAURENT, É. Recherches sur les nodosités radicales des Légumineuses. Ann. Inst. Pasteur, 5:105–139. 1891.
7. LEONARD, L. T. Relation of photosynthetic carbohydrate activity to nodule formation on soybeans. Jour. Amer. Soc. Agron., 18:1012–1016. 1926.
8. MAZÉ, M. Les microbes des nodosités des Légumineuses. Ann. Inst. Pasteur, 12:128–155. 1898.
9. NIGHTINGALE, G. T. The nitrogen nutrition of green plants. Bot. Rev., 3:85–174. 1937.
10. RÜFFER, E. Forschungen zum Kohlenhydratumsatz bei Knöllchentragenden und Knöllchenfreien Sojabohnen. Ztschr. Pflanzenernähr. Düngung, A *24:* 129–167. 1932.
11. STROWD, W. H. Relation of nitrate to nodule production. Soil Science, 10: 343–356. 1920.
12. WEBER, E. Saltpeterdüngung als Beeinträchtigung der Stickstoffsammlung durch Leguminosen. Centbl. Bakt. (etc.) 2 Abt., 82:353–379. 1930.
13. WILSON, P. W. The carbohydrate-nitrogen relation in symbiotic nitrogen fixation. Wis. Agr. Exp. Sta. Res. Bul. 129. 1935.

STUDIES OF BORON DEFICIENCY IN IDAHO SOILS[1]

WILLIAM E. COLWELL AND G. ORIEN BAKER[2]

BORON has been termed a "minor element" because of its requirement in relatively small quantities, but according to Naftel (8)[3] it could be considered a major element from the standpoint of plant nutrition.

Although the necessity of boron in plant growth was discovered by Maze in 1914, it was in 1931 that Brandenburg directed the attention of agriculturists to its use as an artificial fertilizer by showing that under field conditions its deficiency was the cause of heart rot and dry rot in sugar beets.

As far as it is known, the first record of boron deficiency under field conditions in the United States was in Maryland where it was found to produce characteristic symptoms on tobacco plants. This was reported in 1935 by McMurtrey (7). From 1936 to 1938 the fertilizer action of boron was being recognized, and during this period approximately 350 investigations were reported (8). Investigators in many states, including Alabama, California, Connecticut, Florida, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, South Carolina, Vermont, Washington, and Wisconsin, have to date reported response to boron fertilization.

Several excellent reviews of the literature and relatively complete lists of references dealing with the effects of boron on several plants have been compiled by Dennis (3), Dennis and O'Brien (4), Willis (10), and by the American Potash Institute (1).

In 1936, McLarty (5) in Canada showed that boron was the substance effective in preventing drought spot and corky core in apples. Further work in Canada by McLarty, Wilcox, and Woodbridge (6) showed that a certain type of alfalfa yellowing was caused by a lack of boron and that it could be overcome by the addition of either boric acid or borax.

These investigations called attention to the possibility of a similar problem in northern Idaho, for it had been noted for a number of years that certain fields of alfalfa in that area were showing a similar yellowing.

[1]Contribution from the Department of Agronomy, University of Idaho, Moscow, Idaho. A portion of a thesis submitted by the senior author to the graduate school, University of Idaho, in partial fulfillment for the requirements for the degree of Master of Science in Agriculture. Published with the approval of the Director of the Idaho Agricultural Experiment Station as Research Paper No. 180. Received for publication January 25, 1939.

[2]Instructor in Agronomy and Soils Technologist, respectively. The authors wish to express their appreciation to Dr. R. E. Stephensen of Oregon State College for the general plan of the greenhouse work and to Professor J. M. Raeder and Dr. Earle Blodgett of the Department of Plant Pathology of the University of Idaho for their valuable assistance and suggestions.

[3]Figures in parenthesis refer to "Literature Cited", p. 512.

PLAN OF GREENHOUSE EXPERIMENTS

The purpose of the greenhouse investigations was to supplement the field method of determining probable boron deficiency in soils, since the field method is both time-consuming and costly. Five plants were produced in 1 pound of the soil to be tested and all the elements required for normal plant growth, except boron, were added either in a nutrient solution or directly to the soil. The boron must then be supplied by the soil itself. Several cans containing acid-washed quartz sand were included in each experiment for the purpose of checking against boron contamination in the nutrient solution.

The containers used were commercial "No. 1 tall renameled charcoal" cans. The enamel was not destroyed during the growing period so the danger of boron contamination was greatly reduced. The soil was transferred to a new can when a second crop was grown in a soil which had already produced one crop.

Ten sunflower seeds were planted per can and when well established they were thinned to five uniform plants. During early stages of growth, nutrient solution was added alternately with distilled water to keep the moisture content at normal field capacity. Later, when transpiration losses were great, a maximum of 25 cc of nutrient solution were added each day and distilled water was used as often as necessary to keep the moisture content fairly constant. About 30 applications of nutrient solution were made throughout the period of growth. Determinations of soluble salt content in the soils before and after the growing period indicated that their concentration had been increased and in many soils had become quite high. Although no detrimental effects of too high a salt concentration were noted, it seems advisable to reduce the applications of nutrient solution to a minimum. Determinations of pH on the soils before and after the growing period showed no significant change.

Each liter of nutrient solution used contained the indicated number of cc's of each of the following molar solutions: 5 cc KH_2PO_4, 2 cc K_2HPO_4,[4] 7 cc $MgSO_4$, 7 cc $Ca(NO_3)_2$, 7 cc $NaNO_3$.[5]

Manganese sulfate to supply the equivalent of 5 pounds of manganese per acre was added separately to the soil of each can. Boric acid to supply the equivalent of 5 pounds of boron per acre was added to those receiving the complete nutrient solution plus boron.

RESULTS OF GREENHOUSE INVESTIGATIONS

INDICATOR PLANTS

A comparison of tobacco, nasturtiums, sugar beets, and sunflowers was made in an attempt to find which plant would be the most sensitive indicator of boron deficiency. In each case characteristic boron deficiency symptoms developed on the sunflowers sooner than on any of the other three test plants. A pronounced decrease in flowering was noted in the nasturtiums growing in soils receiving no boron,

[4]The stock solution of K_2HPO_4 being used at the present time is only 1/5 molar.

[5]A comparison of two nutrient solutions differing in concentration of nitrogen was made. One contained 7 cc molar $Ca(NO_3)_2$ per liter of solution and supplied 196 p.p.m. of N. The other contained 7 cc molar $Ca(NO_3)_2$ per liter and 14 cc molar $NaNO_3$ per liter, supplying a total of 392 p.p.m. of N. In each case boron deficiency symptoms became apparent from 1 to 8 days earlier on the sunflowers receiving the latter solution. Some soils, however, may have reacted unfavorably to the high concentration of sodium, so in order to avoid danger from this cause the solution finally used was the above.

but this was only apparent some time after the sunflowers had developed definite deficiency symptoms. Tobacco and sugar beets growing in soils receiving no boron each developed characteristic symptoms but only after a relatively long growing period.

Besides producing definite symptoms of boron deficiency during early stages of growth, sunflowers are easily handled in the greenhouse. They are readily started and require no means of support during even the later growing period. As a result of these observations they were used as test plants throughout the remainder of the investigation.

BORON DEFICIENCY SYMPTOMS OF SUNFLOWERS

The first sign of boron deficiency is a yellowing at the base of the young leaves of the growing tip. Soon the entire area of the young leaf turns yellow, then almost white, and dies. The older leaves nearest the growing point begin to yellow at the base and become thickened and drawn and show a tendency to roll in a half circle with the tip pointing toward the stem (Fig. 1). These deformed leaves are a shiny green at the end and shade from yellow to reddish brown at the base. This condition is followed by a drooping of the older leaves and a shortening of the internodes, giving a "rosetted" appearance. The leaves of the flattened top of the plant may be thick and brittle. Necrosis of the terminal growth takes place rapidly and in severe cases the entire center becomes a reddish brown color. If the plant is allowed to grow, the older leaves continue to die until finally a woody stalk bearing drooping, nearly dead leaves is all that remains. In less severe cases the yellowing of the young leaves is not followed by immediate death of the terminal growth but by a mosaic pattern of five or six of the older top leaves. Later these yellow areas, sometimes occurring over the entire surface of the older leaves, have a reddish tinge. Depending on the severity of the case, the younger leaves may or may not thicken, curl downward, and die.

BORON DEFICIENCY AS INDICATED BY ROOT DEVELOPMENT

Although the difference in root size caused by the addition of boron to boron-deficient soils is not a practical means of determining whether or not a soil is deficient in boron, the stimulating effect of boron upon root development is worth mentioning. The difference is shown in Fig. 2. The five roots shown in the upper half of the figure were cut from those plants receiving boric acid at the rate of 5 pounds of boron per acre and those shown in the lower half had received no boron. An even greater difference was noted in the roots from the second foot of the same soil. It has been a common observation throughout the greenhouse studies that the symptoms became apparent first in plants grown in the second foot samples. This difference is shown in Table 1.

EFFECT OF PRODUCING A SECOND CROP IN A SOIL WITHOUT BORON ADDITIONS

After the sunflowers, growing in the first foot of soil, were harvested, four of the soils tested were transferred to new cans and sunflowers

TABLE 1.—*Oven-dry weight of sunflower tops per can and days required to produce first boron deficiency symptoms.**

Soil type	First crop						Second crop first foot	
	First foot			Second foot				
	Days	Check —B, grams	Boron +B, grams	Days	Check —B, grams	Boron +B, grams	Days	Without boron, grams
Quartz sand (check)	19	1.17	4.90	—	—	—	—	—
Springdale coarse sandy loam	26	2.81	7.07	—	—	—	25	1.85
Santa silt loam	31	5.15	8.19	29	3.99	7.54	—	—
Garrison gravelly loam	33	7.11	7.70	—	—	—	32	3.47
Bonner fine sandy loam	36	6.84	8.34	—	—	—	25	3.77
Mission silt loam	38	6.73	9.07	37	6.19	7.43	38	5.53
Helmer silt loam	42	4.57	6.09	35	2.75	5.94	—	—
Moscow loam	42	5.15	5.28	37	3.62	4.80	—	—
Springdale gravelly loam	45	7.43	9.97	39	3.82	6.39	19	0.74
Palouse silt loam	50	7.09	8.73	61	4.86	5.15	—	—

*All first crop data are averages of duplicates and all plants were harvested after 53 days except those growing in quartz sand, Sprindale gravelly loam, and Palouse silt loam which were harvested after 61 days. The sunflowers grown in quartz sand and Springdale gravelly loam were planted on March 15, 1938, while all the others were planted on May 7, 1938. All second crop data are single determinations.

were seeded again. This is referred to as the second crop. At the same time, some of the original of each soil was placed in cans and planted. Boric acid to supply 5 pounds of boron per acre was added to half of

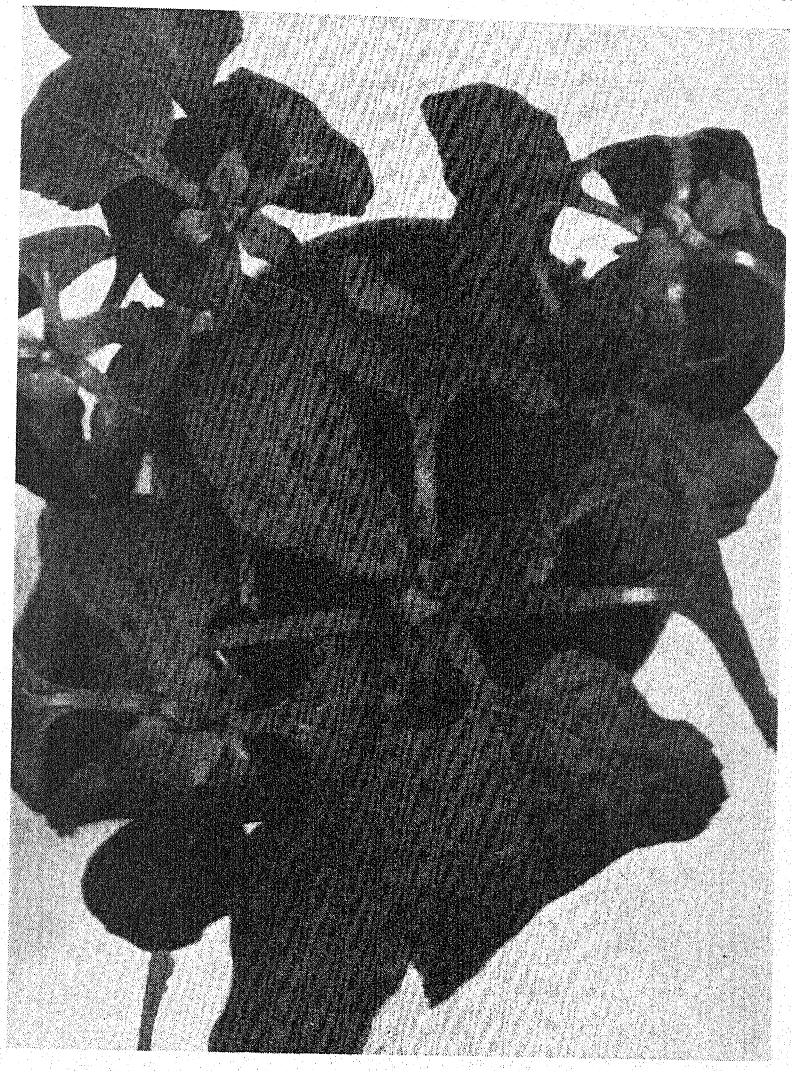

FIG. 1.—Sunflower plants 40 days old growing in Garrison gravelly loam to which all the elements essential for plant growth except boron had been added. Note the dead center of each of the five plants and the drooping of some of the older top leaves.

the new samples and the others served as checks. The growth obtained from the first foot of soil with and without boron and for the second crop without boron on Bonner fine sandy loam is shown in Fig. 3.

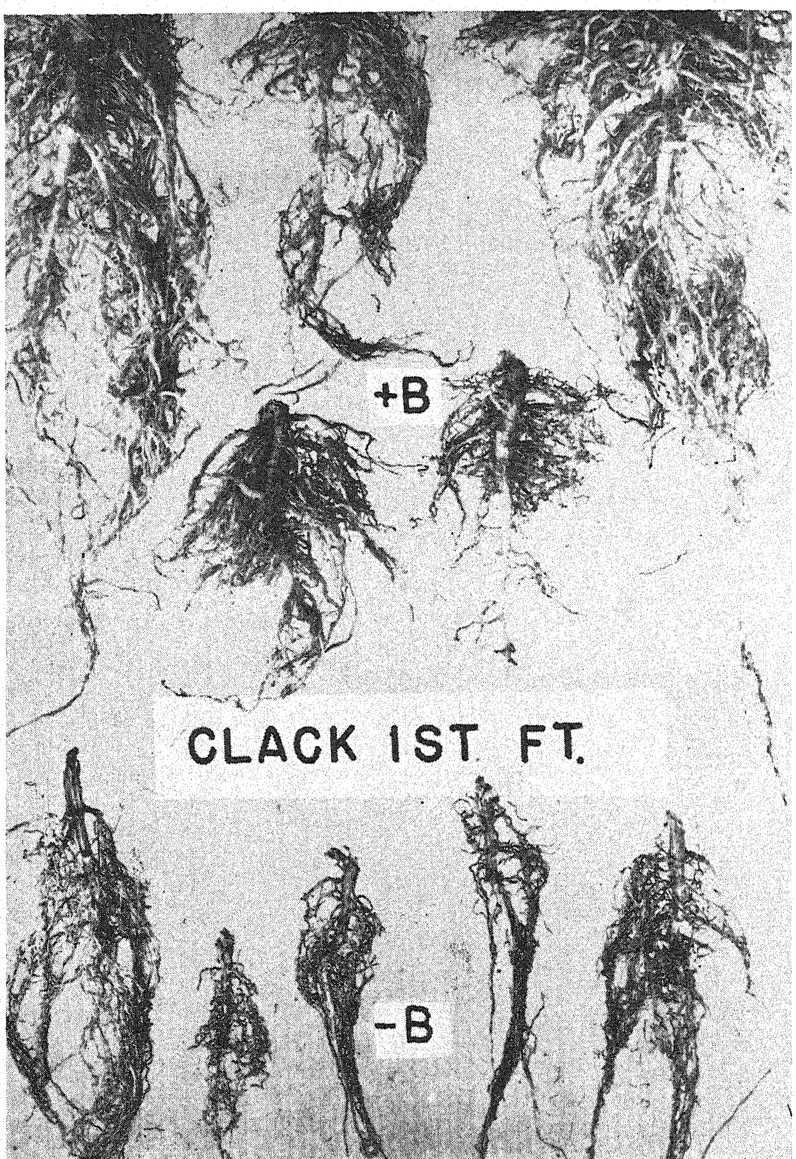

FIG. 2.—Sunflower roots grown in the first foot of Springdale gravelly loam with boron (upper) and without boron (lower). ¾ actual size.

It may be observed from Table 1 and Fig. 4 that sunflowers growing on the second foot of soil develop deficiency symptoms somewhat sooner and make smaller growth than those plants grown in the first foot. It may also be observed that the second crop of sunflowers

grown in boron-deficient soils produce deficiency symptoms somewhat sooner and produce a smaller yield than the first crop grown. This may indicate that most of the available boron has been used by the first crop and that the process of more boron becoming available is too slow to meet the crop requirement. This result is confirmed by field observations where it is noted in most instances in northern Idaho that the second cutting of alfalfa is more seriously affected by yellowing than the first.

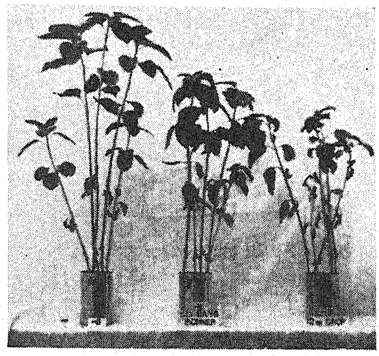

FIG. 3.—Sunflowers growing in a sample of the first foot of Bonner fine sandy loam. The treatments are, from left to right, boric acid added at the rate of 5 pounds of boron per acre, no boron added, and the second crop produced by this pound of soil without boron addition for either crop.

FIELD INVESTIGATIONS

In order to correlate the greenhouse results with those obtained in the field, tests were established in northern Idaho on alfalfa which had shown yellowing the year before. Two tests on different soils, Springdale coarse sandy loam gravelly phase and Helmer silt loam, were designed to compare fall with spring application and also rates of application. In each case, 20, 40, and 60 pounds of borax per acre were applied to 1/20 acre plats in November 1937 and April 1938. The material was mixed with dry sand to add bulk and was broadcast.

Observations made the middle of June just before the first cutting indicated that fall applications were more effective than spring; also that, in the case of the coarser textured soil, a 20-pound application in the fall was insufficient. No yellowing was observed in plats receiving 40 and 60 pounds per acre of borax either in the fall or 60 pounds per acre of borax in the spring. Smaller applications of 18 to 20 pounds of borax per acre on sugar beets have been used with good results by German and Irish workers and, although the rates used in this investigation are higher than those generally used and recommended, no indications of toxicity were noted on the treated plats. Attention has recently been called, however, to the beneficial results obtained from the use of boric acid on alfalfa at the rate of 40 pounds per acre (9).

The increased growth resulting from the addition of borax to alfalfa is shown in Fig. 5 which represents two individual plants grown on a Springdale soil. The untreated plant did not have another plant closer than 3 feet, while the one treated with 60 pounds of borax per acre had three plants within a 1-foot radius. The plant from the check plat was very yellow and the blossom buds were aborted or very small and deformed. On the other hand, the plant from the treated plat was dark green in color and the blossom buds were large and normal.

In the spring of 1937, 10 tests on five soil series were started, using borax at the rate of 40 pounds per acre. June observations before the

first cutting showed a distinct visual difference in seven cases, while in three cases no difference could be observed.

Unfortunately, it was impossible to visit all the tests at the time of the second cutting, but the few observed showed even greater differences than did those which were observed when the first cutting was made. This correlates with the farmers' observations that the second crop is more seriously affected by the yellowing than the first.

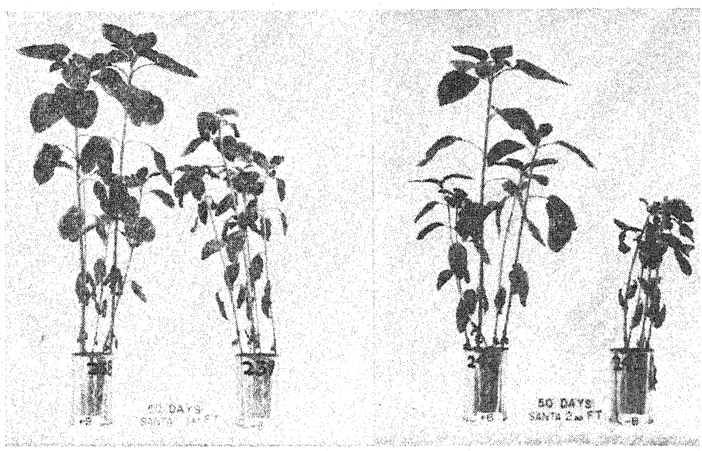

FIG. 4.—Sunflowers growing in a first and a second foot sample of uncultivated Santa silt loam.

DISCUSSION

It appears from this preliminary study that many of the soils of northern Idaho are deficient in available boron for alfalfa. This may be the result of climatic factors, soil development processes, and character of parent materials, all of which had some influence in the formation of these soils.

The mineral tourmaline, which is the most common boron-carrying mineral, is known to occur only in very small quantities in the basalt and the sedimentary strata which underlie most of northern Idaho. Therefore, the material which is a major constituent of the parent material of both glacial and loessial soils of this area would appear to be inherently low in boron.

Tourmaline, however, is known to be quite abundant in the granitic intrusive rocks and in the older sedimentary rocks altered by emanations from the igneous magmas. These materials, however, do not occur in great quantities in the parent material of soils in northern Idaho.[6]

The data show that under the condition tested the sunflower exhibits symptoms of boron deficiency much sooner than either the tobacco, nasturtium, or the sugar beet. Furthermore, the appearance

[6]Personal communication from Dr. A. L. Anderson, Department of Geology, University of Idaho.

of definite and recognizable symptoms offers a more sensitive means of detecting a boron-deficient soil than do differences in weight or in root development between healthy and diseased plants.

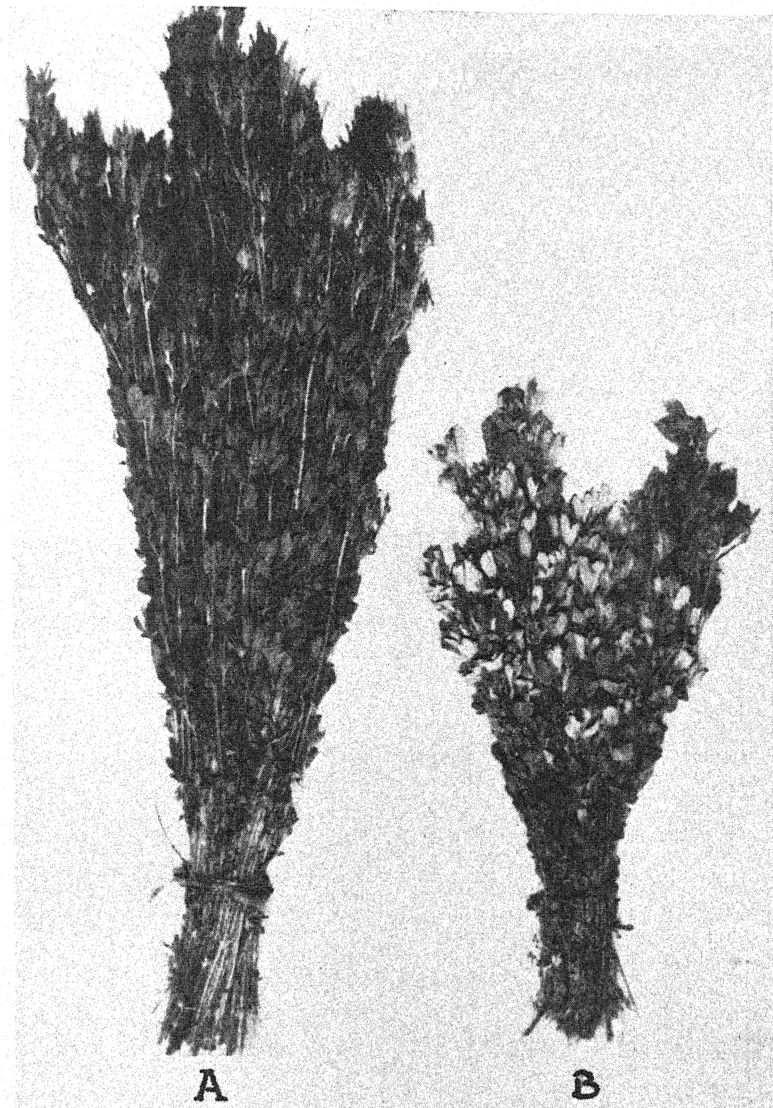

FIG. 5.—Individual alfalfa plants grown on Springdale coarse sandy loam gravelly phase. (A) From plat receiving borax at rate of 60 pounds per acre; (B) from check plat receiving no borax. Note the yellowed leaves and stunted growth of the plant which had not received borax.

It was observed that sunflowers growing in samples of the same soil developed boron deficiency symptoms from one to eight days sooner when a nutrient solution relatively high in nitrate nitrogen was used. Whether this is due to a more luxuriant vegetative growth or whether it is an indication that the function of boron is in some way related to the regulation of nitrate ion absorption or nitrogen metabolism is not known.

Those plants growing in coarse-textured soils deficient in boron developed symptoms of severe deficiency soon after the first recognizable symptoms appeared. In a very few days after this, sometimes only three or four, those plants suffering from a lack of boron were practically dead. Those plants growing in the finer-textured soils often did not develop severe symptoms of the deficiency, and death did not occur in plants growing in any of the fine-textured soils under investigation.

Samples of alfalfa, some showing yellowing and some healthy plants, were analyzed for boron, and a lower content was found in the yellowed plants. Too few samples were analyzed, however, to state definitely that this relationship always exists under northern Idaho conditions.

SUMMARY

1. A greenhouse method suitable to detect boron-deficient soils is described. A good correlation was obtained between greenhouse and field experiments.

2. Preliminary field tests in northern Idaho indicate that fall applications of borax at the rate of 40 to 60 pounds per acre are superior to spring applications in overcoming yellowing in alfalfa.

3. The results of a limited number of analyses on alfalfa indicate that a high boron content of alfalfa is associated with freedom from yellowing.

4. The investigations are of preliminary character. Further work is being done to substantiate these findings.

LITERATURE CITED

1. AMERICAN POTASH INSTITUTE. Boron as a plant nutrient. 1938.
2. ANONYMOUS. Boron and plant life. Fertilizer, Feeding Stuffs and Farm Supplies Jour., Dec. 4 and 18, 1935; Jan. 1 and 29, 1936.
3. DENNIS, R. W. G. Boron and plant life, II: Recent developments in agriculture and horticulture. Fertilizer, Feeding Stuffs and Farm Supplies Jour., Sept. 8 and 22; Oct. 6, and 20, 1937.
4. ———— and O'BRIEN, D. G. Boron in agriculture. West of Scotland Agr. Col. Res. Bul. 5:1. 1937.
5. MCLARTY, H. R. Tree injections with boron and other materials as a control for drought spot and corky core of apple. Sci. Agr., 16:625–633. 1936.
6. ————, WILCOX, J. C., and WOODBRIDGE, C. G. A yellowing of alfalfa due to boron deficiency. Sci. Agr., 17:515–517. 1937.
7. MCMURTREY, J. E., Jr. Boron deficiency in tobacco under field conditions. Jour. Amer. Soc. Agron., 27:271–273. 1935.
8. NAFTEL, JAMES A. Recent studies on boron in soils. Amer. Fert., 89:No. 7. Oct., 1938.
9. POWERS, W. L. The minor elements in soil fertility and plant nutrition. Ore. State Agr. Col., Sta. Circ. of Information No. 192. 1938.
10. WILLIS, L. G. Bibliography of references to the literature on the minor elements and their relation to the science of plant nutrition. New York: Chilean Nitrate Educational Bureau. Ed. 1, 1935; Ed. 2, 1936; Ed. 3, 1939.

THE DIFFERENTIAL RESPONSE OF ALFALFA VARIETIES TO TIME OF CUTTING[1]

H. M. TYSDAL AND T. A. KIESSELBACH[2]

THAT alfalfa responds adversely to too frequent cutting has been rather thoroughly demonstrated in numerous experimental tests. The comparative reaction of different varieties has not been studied to a similar extent, however, and the response of the comparatively new variety Ladak has, as yet, not been reported. Since this variety has shown a rather strikingly different response to cutting treatment, the present report has been prepared showing its yield and stand in comparision with three standard varieties under several cutting treatments during the past five years at the Nebraska Experiment Station.

As a preliminary comparison, Table 1 is presented giving a summary of the yield and maturity at time of cutting Ladak compared to Grimm and Nebraska Common in a number of field plat varietal tests conducted during the period 1929 to 1933. These tests were on two different fields, and considering the number of replications and years involved, averages of 29 different plat yields of each variety are reported in the table. The actual and relative yields are given by cuttings. The cutting treatment in these variety tests may be considered approximately normal for standard varieties for this locality, the first cutting being taken about June 1, the second during the first 10 days of July, and the third usually more than a month later. In general, the Ladak yielded proportionately more than Grimm or Nebraska Common in the first cutting, 57% of the total crop being produced in the first cutting compared with 49% for Grimm and Nebraska Common. Ladak yielded both actually and proportionately less than the other varieties in the second and third cuttings. The high yield of Ladak in the first cutting suggests that it may be a very desirable variety under those conditions where one cutting constitutes the total hay crop. This particular adaptation has been mentioned in other reports.[3]

The maturity at the time of cutting as indicated by the percentage of bloom, shows that Ladak is more immature at the second and third cutting under these conditions of harvest than the other two varieties although there is not much difference in the first cutting.

TIME-OF-CUTTING EXPERIMENT

In August, 1932, a new set of field plats was sown to four varieties—

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr., as Journal Series Paper No. 226. Received for publication January 28, 1939.

[2]Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Agronomist, Department of Agronomy, Nebraska Agricultural Experiment Station, respectively.

[3]WESTOVER, H. L. Alfalfa varieties in the United States. U. S. D. A. Farmers' Bul. 1731. 1934.

TABLE 1.—*Mean annual yield per acre from the various cuttings of Ladak, Grimm, and Nebraska Common alfalfa, and the stage of maturity at time of cutting as compiled from two variety tests during four years, 1929–1933.*

Cutting	Grimm	Nebr. Common	Ladak
Tons Per Acre by Cuttings, 15% Moisture			
1st	1.67	1.57	1.96
2nd	1.10	1.00	0.98
3rd	0.63	0.60	0.52
Total	3.40	3.17	3.46
Relative Yield by Cuttings, Total for Season = 100			
1st	49	49	57
2nd	32	32	28
3rd	19	19	15
Total	100	100	100
Maturity at Time of Cutting as Indicated by Per cent Bloom			
1st	7	3	8
2nd	67	52	46
3rd	58	49	39
Average	44	35	31

Grimm, Nebraska Common, Hardistan, and Ladak—each replicated 24 times. In 1933 all plats were cut at the same time, the first cutting not being taken until June 21, the second July 29, and the third September 6. These dates constitute much later cuttings than normal and in Table 2 these are referred to as "late" cutting, with respect both to the date of the first cutting and the intervals between cuttings.

In 1934 these replicate plats were grouped for cutting at two stages of maturity. Five plats of each variety, designated as "early" cutting (Table 2) were cut on the successive dates of May 17, June 16, and July 10. The remaining plats, 17 of each variety, were cut June 7 and July 6, designated as "medium" cutting. The field was in its prime and despite the severe drought yielded an average of more than 3 tons of cured hay per acre in two cuttings. In all treatments Grimm and Nebraska Common responded very similarly and there was no significant difference in their yields as calculated from a generalized error by variance.

On the other hand, in 1933, with the late cutting treatment, Ladak yielded 108% of Grimm which is significantly higher. In the medium cutting treatment in 1934 it yielded about the same as Grimm, but in the early cutting treatment of 1934 it yielded only 83% as much as Grimm, an amount very significantly lower than Grimm or Nebraska Common.

In 1935 the plats were again cut at different times, some of them being cut twice, some three times, and some four times. In no case were there less than three replicates of each variety or more than seven. The yields from these cuttings are also given in Table 2, together with the dates of cutting. In all of the late and medium-late

TABLE 2.—*Comparative yields of four alfalfa varieties cut at different dates during the years 1933–35.*

Time of cutting	Year	Actual yield, tons per acre				Difference for significance, tons	Yield relative to Grimm			
		Grimm	N. W. Nebr. Common	Hardistan	Ladak		Grimm	N. W. Nebr. Common	Hardistan	Ladak
Late[1]	1933	2.56	2.61	2.60	*2.76*[9]	0.07	100	102	102	108
Medium[2]	1934	3.21	3.22	*3.15*	*3.15*	0.05	100	100	98	98
Early[3]	1934	3.35	3.42	3.29	*2.79*	0.12	100	102	98	83
Late[4]	1935	3.20	3.06	*2.94*	3.31	0.22	100	96	92	103
Late[5]	1935	2.73	2.68	2.68	2.92	0.22	100	98	98	107
Medium late[6]	1935	2.81	2.70	2.82	*3.24*	0.14	100	96	100	115
Early[7]	1935	2.88	2.79	*2.67*	*2.69*	0.16	100	97	93	93
Early[8]	1935	3.10	3.15	*2.87*	*2.78*	0.22	100	102	93	90

[1]Late cuttings made June 21, July 29, and Sept. 6, 1933.
[2]Medium cuttings made June 7 and July 6, 1934.
[3]Early cuttings made May 17, June 16, and July 10, 1934.
[4]Cuttings made June 24, August 2, and Sept. 10, 1935.
[5]Cuttings made June 24 and August 2, 1935.
[6]Cuttings made June 12 and July 12, 1935.
[7]Cuttings made June 3, June 25, and July 25, 1935.
[8]Cuttings made June 3, June 25, Aug. 2, and Sept. 10, 1935.
[9]The yields which are significantly different from Grimm appear in italic.

cuttings Ladak is the highest-yielding variety, whereas when the varieties were cut early it is lowest when four cuttings were taken and next to the lowest with three cuttings, in both cases being significantly lower than Grimm.

Thus, in the same group of plats, Ladak is the highest-yielding variety under one cutting treatment, while under another it is the lowest.

YIELD BY CUTTINGS

With reference to the production in different cuttings of the same year it can be seen from Table 3 that Ladak responds very differently from the other varieties, depending not only on the time of the first cutting but also on the interval between cuttings. For example, when harvested at an early stage throughout the season, Ladak produced very little more than Grimm in the first cutting and very much less than Grimm in the second cutting. The difference was usually even greater in the third cutting. On the other hand, by leaving the first cutting late the Ladak increased its advantage over Grimm, in this instance to 0.37 ton per acre or 22%, and if a rather long interval was allowed to elapse before the second cutting was taken Ladak yielded almost as much as Grimm. This was also true of the third cutting. For example, in the third cutting of 1933 when a relatively long interval was left between the second and third cuttings, Ladak produced as much as Grimm. The usual interval between cuttings may be considered approximately one month in this territory, and a relatively long interval would be 40 days or more, this depending however on a large number of factors. From observation it is apparent that Ladak starts growth much more slowly than Grimm after cutting, but from results of delayed cutting it appears that once it does start it grows more rapidly than Grimm, particularly as it approaches the harvest stage. It also appears that Ladak retains its leaves somewhat longer than the other three varieties as it approaches maturity due to its greater leaf-spot resistance and possibly other factors, thus maintaining its hay quality relatively better in the more mature stages.

TABLE 3.—*Yield, in tons per acre, of Ladak and Grimm alfalfa in the first and second cuttings as influenced by time of cutting, average of 1934 and 1935 crops.*

Time of cutting*	Yield, tons per acre (15% moisture)					
	1st cutting			2nd cutting		
	Grimm	Ladak	Difference in favor of Ladak	Grimm	Ladak	Difference in favor of Grimm
Early	1.44	1.54	0.10	1.01	0.71	0.30
Medium	1.73	2.04	0.31	1.29	1.16	0.13
Late	1.65	2.02	0.37	1.14	1.03	0.11

*Applies to both first and second cuttings.

MATURITY AT TIME OF CUTTING

At the time of cutting the various plats the estimated percentage bloom was recorded, considering full bloom as 100%. Tables 1 and 4 show that Ladak was about as mature in the first cutting as any other variety, whether cut early or late, but in the second and third cuttings Ladak usually was far behind in percentage of bloom. Even when an unusually long time elapsed between cuttings Ladak did not approach the maturity of Grimm. In the second cutting of 1935, with a medium interval between cuttings, Ladak had an average percentage bloom of only 18, while Grimm had 61% bloom. In the third cutting of 1933 which was exceptional in that Ladak yielded practically the same as Grimm, the latter had 16% bloom, while Ladak had only 5% bloom. Of the four varieties under consideration, Grimm generally has the most profuse bloom, Nebraska Common second, and then Ladak or Hardistan depending on the cutting. Hardistan usually has less profuse bloom than any of the other varieties in the first cutting, but usually blooms somewhat more than Ladak in the second and third cuttings.

TABLE 4.—*Maturity at time of cutting four alfalfa varieties as indicated by percentage of bloom, 1935.*

Time of cutting*	Percentage bloom at							
	1st cutting				2nd cutting			
	Grimm	N. W. Nebr. Common	Hardistan	Ladak	Grimm	N. W. Nebr. Common	Hardistan	Ladak
Early......	2	1	0	2	0	0	0	0
Medium...	14	11	4	8	61	41	36	18
Late.......	69	58	40	65	—†	—†	—†	—†

*Same dates as in Table 2.
†Estimate of percentage bloom not possible because of blasting of buds.

EFFECT OF CUTTING TREATMENT ON STAND SURVIVAL

One of the important questions relating to time of cutting is that of stand survival. While it is not the purpose of this paper to report in detail the influence of cutting on stand, certain stand counts were obtained which might prove of interest. In the fall of 1938 the plats whose yields are reported in Table 2 were plowed and at this time counts were made of the plants occurring in a strip 2 inches wide along the edge of a furrow extending across the plats. From 8 to 10 such counts were made on each plat, and since there were at least three plats of each treatment the average counts reported in Table 5 are the average of approximately 27 determinations. The stands per acre are reported in thousands, and a significant difference in the readings was calculated by the variance method to be 54 (000).

While the stands, on the whole, were very good at the end of the six-year period, some of the plats with the lowest stand count were beginning to thin and were given estimated stands of less than 90%.

The interesting feature of Table 5 is the difference shown in the response of the varieties. Ladak and Hardistan, both somewhat more cold resistant and wilt resistant than Grimm or Nebraska Common, do not show a significant difference in stand count between the early, frequent cutting treatment and the late cutting treatment. Both Grimm and Nebraska Common show a significant difference between these treatments. Ladak shows a significant difference between the first cutting early treatment and the late cutting treatment, which might indicate that Ladak is somewhat handicapped when it has the first cutting, which is normally its largest cutting, taken off prematurely. Nebraska Common is the only variety which has a significant difference between the early cutting treatment and the first cutting early treatment, which may again point out the greater susceptibility of this variety to severe cutting treatments.

TABLE 5.—*Stand counts of plants per acre made in 1938 on plats planted in 1932 and subjected to different cutting treatments from 1933 to 1937, inclusive.*

Time of cutting	Thousands plants per acre*			
	Grimm	Nebraska Common	Hardistan	Ladak
Early throughout	352	324	437	426
First cutting early, others medium	386	393	437	400
Medium	399	405	459	432
Late	435	424	471	470

*Difference necessary for statistical significance between any two readings = 54 (000).

CONCLUSIONS

The response of Ladak to different times of cutting is so great that it may almost be said that this variety can be made the lowest or highest yielding in a series of standard varieties through change in the time of cutting. In these experiments, when the first cutting was late and subsequent cuttings had a relatively long time to develop, Ladak was significantly higher in yield than any of the other three varieties tested. When it was cut unusually early it was significantly lower in yield than Grimm in all comparisons, and equally low or significantly lower than the other varieties, Nebraska Common and Hardistan.

In contrast to this, Nebraska Common was not significantly different in yield from Grimm under any cutting treatment and Hardistan reacted rather similarly to Grimm, although somewhat lower in yield under some treatments than others. Early cutting appears to handicap Hardistan slightly in comparison to Grimm.

The logical question arising from these results is whether it is necessary to harvest varieties at different times in an ordinary variety test to secure accurate comparisons, and, if so, what criteria are going to determine the time of cutting. While it is not the purpose of this paper to go into this question fully, it seems desirable that in at least some varietal tests adequate attempts be made to obtain a knowledge of cutting treatments for optimum production of different varieties.

The exact criteria as to when to cut the varieties for optimum production is a more difficult question. While the percentage bloom is of some value as an index to stage of maturity, it is subject to so many factors, both ecological and physiological, that it is often impossible to judge the relative maturity of varieties by this method. For example, Ladak and Hardistan seldom bloom as profusely in late summer as Grimm or Common in this territory; hence if Grimm were left to a medium percentage bloom before cutting, it is unlikely that the former two varieties would reach a similar degree of bloom. Often the time to cut is determined by the beginning of new growth at the crown. While it has been observed that Ladak starts growth more slowly from the crown, which would correlate with the desired delayed cutting practice, insufficient data are available to indicate whether this would make a reliable criterion.

Since it is so difficult to judge exact maturity in alfalfa varieties, it is suggested that a desirable practice might be to plan certain tests so that replicate plats could be harvested at different intervals, all of the varieties being cut at the medium-early stage, for example, while another group of plats would be cut at a later stage throughout. In this way a correct rating of the varieties could be obtained, and in addition proper recommendations for the commercial handling of the crop could be made. The results of this study indicate, for example, that, barring the intrusion of certain disease and insect pests, Ladak should be allowed to grow somewhat longer for the first cutting and between subsequent cuttings than is usually the case with Grimm or Common for optimum production either in variety tests or on the farm.

THE RESPONSE OF LESPEDEZA TO LIME AND FERTILIZER[1]

R. E. STITT[2]

THE annual lespedezas have become established as hay, pasture, and soil-improvement crops in many of the southern states. The general experience of farmers with the annual varieties of common lespedeza (*Lespedeza striata*) (*Thunb.*) *H.* & A.) and Korean (*L. stipulacea* Maxim.) and the perennial sericea (*L. sericea* (Thunb.) Benth.) has shown that they are adapted to soils on which other legumes will not grow without considerable expense for lime and fertilizer. Although the lespedezas will grow on so-called poor soils there is some evidence indicating that the use of fertilizers under certain conditions may be beneficial.

In pot experiments, Hyland (5)[3] studied the growth of Korean and sericea lespedezas as compared with red clover and sweet clover on four acid soil types in which the pH was raised to different levels by applying calcium carbonate. Sericea was slightly more tolerant of higher acidity than Korean lespedeza. Soil pH readings were not true indicators of the adaptation of any of the legumes to the soils studied.

In west Tennessee Essary (2) reports increases in yield of common lespedeza from the use of lime but commercial fertilizers did not influence yields to an appreciable extent.

Blair (1) in North Carolina reports the average yield of four different varieties of lespedeza on an Alamance gravelly silt loam to be higher with lime and superphosphate treatments than on the untreated plats.

Pieper, *et al.* (7), in southern Illinois, increased the yield of Korean lespedeza on several soils with applications of limestone and crop residues and also concluded that some soils need phosphate for lespedeza.

In Missouri the yield of Korean lespedeza was increased with superphosphate but decreased with application of 3 tons of lime according to Etheridge, *et al.* (3).

On a Berks shale soil in Virginia, Gish and Hutcheson (4) increased the yield of Korean lespedeza with both lime and superphosphate.

At the Kentucky Agricultural Experiment Station (6) analyses were made of 34 lespedeza hay samples and found that all from poorer soils were low in phosphorus. Lime and phosphates increased hay yields on a sandstone soil at the western Kentucky substation, however, no increased growth was found with lime and fertilizer treatments on a limestone soil.

These few experimental results over a widespread area indicate that lime and phosphates may be beneficial to lespedeza on some soil types. Previous fertilizer treatment and the type of rotation seem not to have been considered in these experiments which raises the question of the desirability of applying fertilizer to lespedeza when fertilizer has been used with other crops in the rotation. The first experiment

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the North Carolina Department of Agriculture and the North Carolina Agricultural Experiment Station. Received for publication February 9, 1939.

[2]Assistant Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 527.

herein reported was conducted in order to determine this point more fully and the second in order to determine the effect of fertility level on the different varieties of lespedeza.

LESPEDEZA IN ROTATION WITH FERTILIZED CROPS ON A FERTILE SOIL

The effect of lime and fertilizer on Korean and Kobe lespedeza when grown in an oat-lespedeza rotation on a Cecil loam was studied in an experiment conducted during 1931 at Statesville, North Carolina. The field on which the experiment was conducted had not previously received lime, but applications of a complete fertilizer had been made to crops in previous years including 1930 when oats was grown. Plats on which lespedeza was grown in 1931 were laid out in triplicate on two areas on this field, one area receiving no lime and the other one ton of limestone per acre. The fertilizer treatments for the lespedeza plats were 400 pounds of 2–10–4,[4] 200 pounds of superphosphate containing 16% phosphoric acid, 100 pounds manure salts containing 20% potash and 500 pounds of basic slag containing 8% phosphoric acid per acre.

The results of the different treatments are shown in the hay yields from these plats as given in Table 1. When the averages only are con-

TABLE 1.—*The effect of lime and fertilizers on yield of hay of Korean and Kobe lespedeza grown on Cecil loam soil at Statesville, North Carolina, during 1931.*

Treatment	Hay yields in pounds per acre, 12% moisture							
	No lime				Lime			
	Replication			Average	Replication			Average
	1	2	3		1	2	3	
				Korean				
No fertilizer	503	1,030	907	813	743	1,012	1,068	941
400 lbs. 2–10–4	719	1,886	731	1,112	620	1,517	1,103	1,080
200 lbs. 16% superphosphate	787	1,372	1,027	1,062	725	1,162	1,035	974
100 lbs. 20% manure salts	618	1,151	1,186	985	939	1,031	1,253	1,074
500 lbs. 8% basic slag	636	1,408	1,364	1,136	637	1,480	1,035	1,051
				Kobe				
No fertilizer	2,003	1,617	2,182	1,934	2,564	2,081	2,367	2,337
400 lbs. 2–10–4	1,673	1,542	1,889	1,701	1,941	2,755	1,806	2,167
200 lbs. 16% superphosphate	1,802	1,736	1,884	1,807	2,181	2,444	1,974	2,200
100 lbs. 20% manure salts	1,590	1,282	1,628	1,500	2,000	2,522	2,393	2,305
500 lbs. 8% basic slag	2,495	1,486	2,344	2,108	1,853	1,623	1,858	1,778

[4]The fertilizer analysis is given in the order of nitrogen, phosphoric acid, and potash.

sidered these data indicate that some increase in yield of the Korean variety was due to phosphate and the complete fertilizer on the unlimed area. However, inspection of the individual plat yields shows more variation between plats within a treatment than between treatments, indicating the increases are not significant. The same variation within treatments holds true on the limed area of Korean and on both areas of Kobe. However, there was no consistent variation due to treatment, as the treated plats are lower or very little higher in yield than the untreated plats. The yields of Kobe on the limed area are higher than those on the unlimed area with the exception of the yield on the basic slag treatment. As this experiment was carried on for only one year on a soil type that is quite heterogeneous, the data have not answered the question of fertilizer application in the rotation but indicate a need for additional research.

EFFECT OF FERTILIZER APPLIED TO LESPEDEZA GROWN ON AN UNPRODUCTIVE SOIL

The area selected for the experimental work was a Cecil gravelly loam soil near China Grove, North Carolina, which had been planted to Korean lespedeza during 1931 and 1932 with complete failure to obtain stands. During both seasons the lespedeza plants grew to be about 1 or 2 inches high, became yellowish in color with red leaf margins and stems, after which most of them died. In the spring of 1933 experimental plats were laid out on this field. The field was divided into five blocks with ground limestone broadcast on the first, third, and fifth blocks at the rates of 1, 2, and 3 tons per acre, respectively, the second and fourth blocks being left unlimed. The field was then divided into four areas for seeding to Korean, Kobe, common, and sericea lespedeza, each of which crossed the lime and unlimed blocks. The fertilizers were applied in triplicate strips across the limed and unlimed blocks for each of the lespedeza varieties. The fertilizer treatments were a 2–10–4, and 0–10–4, an 0–10–0, and an 0–0–4. A strip was left without fertilizer in each replicate. The fertilizer constituents were 62 pounds of ammonium sulfate, 388 pounds of 16% superphosphate, and 50 pounds of muriate of potash. The plats which did not set sufficient seed for volunteering during 1933 were reseeded in the spring of 1934. This reseeding was the only treatment during 1934.

Determinations of the pH as given in Table 2 were made with a quinhydrone electrode from samples collected in May 1933, about two months after fertilizer and lime applications. The pH values of the superphosphate plats were between 5.0 and 5.5, of the untreated plats between 5.3 and 5.7, and of the limed plats between 5.4 and 6.8. Most of the limed plats were above pH 6. There was apparently a slight increase in the soil acidity with the use of superphosphate either with or without lime. The pH of all the limed plats was higher than that of many fields which have successfully grown lespedeza in this same locality.

During both 1933 and 1934 the Korean and Kobe varieties emerged to good stands on all plats. The germination of common lespedeza

TABLE 2.—*The pH values of Cecil loam soil with different lime and phosphate treatments as determined on soil samples from plats collected in May 1933.*

Treatment	pH values	
	Korean	Kobe
No treatment	5.44	5.53
P	5.19	5.33
1 ton lime	6.40	6.02
2 tons lime	6.44	6.52
3 tons lime	6.45	6.44
P and 1 ton lime	6.20	5.98
P and 2 tons lime	6.08	6.48
P and 3 tons lime	6.46	6.25

was uniformly poor in 1933 but good in 1934. Stand estimations at the end of each season are given in Table 3. In May and June 1933 the stands of Korean were lowered to 40% on the check plats, as compared with 78 to 86% on the phosphate-treated plats, and 60 to 83% on the limed plats. Stands of Kobe were about 90 to 91% on the plats not treated with phosphate, but where phosphate was applied they were nearly perfect. Due to poor germination of the common variety the effects of the fertilizer treatments on stands, if any, were obscured.

TABLE 3.—*Stands in percentage of ground cover of lespedeza grown on Cecil gravelly loam soil with different fertilizer and lime treatments as determined in September 1933 and 1934.*

Treatment	Stand in percentage ground cover						
	Korean		Kobe		Common		Sericea, 1934
	1933	1934	1933	1934	1933	1934	
No treatment	40	5	90	24	55	0	50
K	40	8	91	31	52	0	50
P	78	33	99	54	60	0	73
PK	86	40	99	57	69	0	89
NPK	86	40	99	57	61	0	84
1 ton lime	72	57	90	80	15	80	85
2 tons lime	60	58	87	67	82	0	100
3 tons lime	83	100	98	50	75	0	100
K and 1 ton lime	75	60	90	75	13	85	90
K and 2 tons lime	63	67	90	58	52	0	100
K and 3 tons lime	80	92	97	67	65	0	100
P and 1 ton lime	90	93	100	100	32	75	100
P and 2 tons lime	88	100	98	92	87	0	100
P and 3 tons lime	99	100	100	58	68	0	100

As sericea is a perennial and full growth is not attained during the year of seeding, stand and growth determinations are given only for 1934. Stands of sericea averaged 50% on untreated plats compared with from 73 to 85% with phosphates and 85 to 100% on the limed plats. With both lime and superphosphate stands were perfect.

May 1934 was extremely dry, thus giving a test of drought resistance on a poor soil. The plants of the common variety all died regardless of treatment, the only survival being on a part of the field which had received more or less fertilizer in recent cultivation.

Kobe survived somewhat better than Korean on the untreated plats having a stand of 24% compared with 5%. This ability of Kobe to survive held true for the treated plats also, except for a part of the field which was so located as to receive more moisture due to lack of drainage.

The height of all varieties showed a significant increase to treatment with superphosphate. The Korean variety responded to lime treatment by an increase in height as compared with the unlimed plats. Lime had some effect on Kobe and common also, although the correlation coefficients were not significant.

The plants of all varieties on the plats not receiving phosphates were retarded in growth from the time of emergence until they reached a height of from 1 to 6 inches when growth stopped and many of the plants died. Fig. 1 shows the relative growth of plants of common collected at random from the different treatments on June 7, 1933. These plants were representative of the ones of the other annual varieties at the time the plants were collected. The plants of Korean without treatment stopped growth at about this stage when from 1 to 3 inches high. Kobe and common plants on untreated plats con-

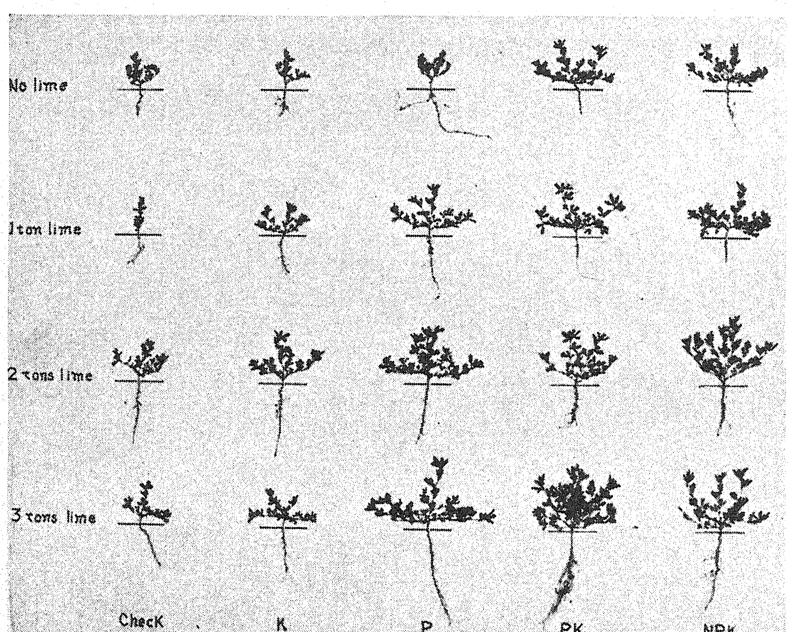

FIG. 1.—Comparative growth of common lespedeza on unproductive Cecil gravelly loam with different fertilizer and lime treatments.

tinued to grow until early in July, while those of sericea grew until August. Comparative growth on September 15, 1933, of Kobe with and without phosphate on the area receiving 2 tons lime is shown in Fig. 2.

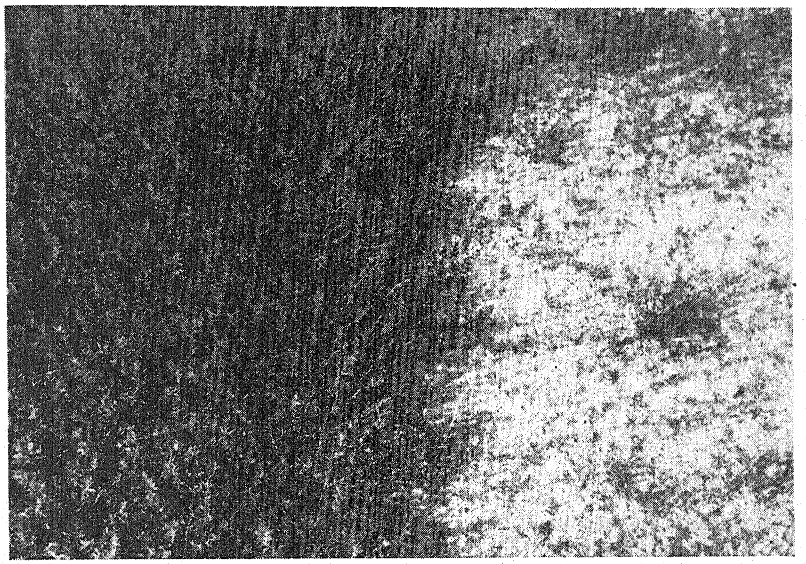

FIG. 2.—Comparative growth of Kobe lespedeza on unproductive Cecil gravelly loam with and without phosphates on the area receiving 2 tons of ground limestone. Left, phosphate; right, potash.

As shown in Table 4 Korean reached a height of 1 to 3 inches, according to the year, on the untreated plats compared with 4 to 6 inches on the superphosphate plats, 4 to 13 inches on the limed plats, and 9 to 17 inches where both lime and superphosphate were used. Kobe and common were from 4 to 6 inches high on the untreated plats, 9 to 11 inches with superphosphate, 6 to 8 inches with lime, and 8 to 16 inches with both lime and superphosphate. Due to the lack of stands of the common variety during the second season, growth could not be measured.

Sericea as measured at maturity in the second season of growth was 16 inches high without phosphate, 26 inches with phosphate; 20 inches with 1 ton, 25 inches with 2 tons, and 30 inches with 3 tons of lime; and 30, 35, and 40 inches, respectively, where phosphate was added with the lime.

Samples of the Korean and Kobe varieties were cut on September 22 and analyzed for ash, calcium, phosphorus, and crude protein. The analyses are given in Table 5. The percentage of calcium was raised by both lime and superphosphate treatments. Phosphorus was higher in the plants from superphosphate plats than in those from the check and lime plats. Crude protein was slightly higher from

TABLE 4.—*Height of lespedeza grown on Cecil gravelly loam soil with different fertilizer and lime treatments as measured in September 1933 and 1934.*

Treatment	Height in inches						
	Korean		Kobe		Common		Sericea, 1934
	1933	1934	1933	1934	1933	1934	
No treatment	3	3	6	4	6	—	16
K	3	1	6	5	6	—	16
P	6	4	10	10	9	—	26
PK	7	4	10	11	10	—	26
NPK	7	4	10	11	10	—	25
1 ton lime	6	6	8	8	6	6	20
2 tons lime	4	5	6	6	6	—	25
3 tons lime	9	13	8	8	8	—	35
K and 1 ton lime	6	6	8	8	6	5	20
K and 2 tons lime	4	5	7	6	7	—	25
K and 3 tons lime	7	12	8	7	8	—	35
P and 1 ton lime	9	11	11	16	8	11	30
P and 2 tons lime	8	12	11	13	10	—	35
P and 3 tons lime	10	17	12	10	11	—	40

the limed plats and very much higher from the superphosphate plats. The protein content of Korean was much higher than Kobe which cannot be accounted for on the basis of these analyses.

TABLE 5.—*The effect of soil amendments on the ash, calcium, phosphorus, and crude protein content of lespedeza, grown on Cecil gravelly loam soil from analyses of samples collected in September 1933.*

Treatment	Percentage on dry matter basis							
	Korean				Kobe			
	Ash	CaO	P_2O_5	Crude protein	Ash	CaO	P_2O_5	Crude protein
No treatment	5.84	0.63	0.38	10.38	4.20	0.68	0.19	9.95
Superphosphate	5.30	0.82	0.47	17.19	4.50	1.09	0.28	13.75
2 tons lime	4.77	0.99	0.25	12.81	4.72	1.03	0.22	11.19
2 tons lime and superphosphate	4.10	0.86	0.45	17.00	4.86	1.09	0.31	14.00

SUMMARY

1. On a Cecil loam soil which had received a complete fertilizer during the previous season Korean lespedeza did not give a significant response to lime and fertilizer and Kobe lespedeza responded slightly to lime.

2. On a Cecil gravelly loam soil, which was too poor for normal growth without treatment, Kobe, Korean, common, and sericea lespedeza responded to phosphate and lime. The Korean variety responded more to lime than either Kobe or common.

3. In their ability to survive drought under conditions of low phosphate availability the varieties ranked with Kobe first, Korean

second, and common third. Common seemed unable to survive drought with the level of fertilizer treatment provided. *Lespedeza sericea* with its perennial root was not affected by the drought.

4. The calcium and crude protein content of Kobe and Korean lespedeza plants growing on the Cecil gravelly loam were increased by the addition of both lime and superphosphate. The phosphorus content was increased by application of superphosphate.

LITERATURE CITED

1. BLAIR, E. C. Lespedeza hay yield increased by superphosphate Phosphorus Digest, 1931 (March):8–10. 1931.
2. ESSARY, S. H. Lespedeza. Tenn. Agr. Exp. Sta. Bul. 123. 1921.
3. ETHERIDGE, E. C., HELM, C. A., and KING, B. M. Korean lespedeza in Missouri. Mo. Agr. Exp. Sta. Bul. 280. 1930.
4. GISH, P. I., and HUTCHESON, T. B. Field crops on Berks shale soil respond to lime and fertilizers. Va. Agr. Exp. Sta. Bul. 292. 1923.
5. HYLAND, H. L. Comparison of legume growth in different soil types at varying acidity levels. Jour. Amer. Soc. Agron., 30:111–121. 1938.
6. COOPER, F. P. [Lespedeza hay.] Ky. Agr. Exp. Sta. Ann. Rpt., 48:57, 61. 1936.
7. PIEPER, J. J., SEARS, O. H., and BAUER, F. C. Lespedeza in Illinois. Ill. Agr. Exp. Sta. Bul. 416:301–347. 1935.

COMPOSITION OF BARK AND INNER PART OF ROOTS OF THE COTTON PLANT[1]

L. E. Hessler, D. R. Ergle, N. E. Rigler, and J. E. Adams[2]

The Division of Soil Fertility Investigations, Bureau of Plant Industry, has studied for a number of years the relation of crop residues, tillage, and crop management to production of cotton under root-rot conditions in the Blackland prairie section of Texas. Correlated laboratory studies have been made of the composition of the cotton plant as influenced by the stage of development and by fertilizer treatment.

Root-rot of cotton is caused by a root-infecting fungus, *Phymatotrichum omnivorum* (Shear) Duggar. Evidence of chemical action, by secretions of the fungus, as a factor of entry into the host plant (14)[3] centers attention on the composition of the root tissue which would serve as the nutrient medium for the growth of the fungus. In previous publications (2, 3), results were presented showing the changes in concentration of certain electrodialyzable and carbohydrate fractions of the roots and tops of the cotton plant at successive stages of growth. The results demonstrated, among other facts, that the nitrogenous fractions of the plant reflected soil conditions, fertilizer treatments, and seasonal variations better than the total nitrogen. The carbohydrates of the cotton plant were also influenced by soil fertilization, but the effects on the nitrogen and phosphorus contents were even more pronounced. The roots contained comparatively high concentrations of carbohydrates.

Additional data (4, 11) concerning the composition of whole cotton plants grown on two soils indicate that there are fairly definite changes in certain nitrogenous and carbohydrate fractions accompanying each stage of growth, namely, the seedling, early squaring, boll set, and boll-opening periods. The composition of the whole plant, however, was not as good a measure of fertilizer effects as that of the tops or roots analyzed separately (2, 3). This was particularly true for the effect of fertilizers on the concentrations of the carbohydrate fractions.

Field tests (7) have shown that high-phosphate fertilizers tend to increase root-rot on both the Wilson fine sandy loam and Houston black clay soils, while high-nitrogen fertilizers tend to decrease the amount of root-rot. The reduction was not significant on the heavier and more calcareous soil. Correlated laboratory studies (11) showed that the composition of the cotton plants was affected by the fertilizers used.

This report deals with the composition of root segregates, i. e., the bark and inner portion, stele, at different dates of sampling during the 1936 season and under varied fertilizer treatment.

[1]Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication February 17, 1939.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 539.

PLAN OF EXPERIMENT

The roots used in this investigation were obtained from cotton plants grown in an experiment designed to study the relationship between fertilizer treatment, yield of cotton, and the occurrence of root-rot under field conditions.[4] The experiment was located on Wilson clay loam soil near Elgin, Texas. The following fertilizer treatments were replicated five times on plats which were randomized according to Fisher (5). The fertilizers used were 0–15–0[5], 3–9–3, 9–3–3, and 15–0–0; untreated check plats were included. The fertilizers were applied at the rate of 900 pounds per acre simultaneously with the planting of the experiment to cotton. Samples secured for each of the treatments consisted of a composite of an equal number of plants from each of the five replications. Morphological and other data from this experiment have been given previously in detail (7). This study covers the period from early square formation to the time bolls were opening.

The procedures for sampling of the plats and preparation of the material for analysis were the same as those given in previous publications (2, 3). For this study the bark was separated from the inner portion of the root by peeling, and each portion was treated as a separate sample. Due to the small size of the plants, samples were not collected before the appearance of squares. The severity of root-rot infestation made it inadvisable to sample after bolls began to open.

METHODS OF ANALYSIS

The analytical procedures have been given in detail in previous publications (2, 3), but are briefly repeated here.

CARBOHYDRATES

The sugars were extracted from the plant tissue with boiling 80% alcohol. The water solution, prepared from the alcoholic extract, was clarified and made to a definite volume. In determining the concentration of sugars, an aliquot of the solution was oxidized according to the Munson-Walker procedure (1), and the reduced copper determined by the Schaffer-Hartmann (12) method. The reducing power before inversion, calculated as invert sugars, was taken as a measure of the total content of reducing sugars. The reducing power, after the oxidation of the aldose sugars by the procedure of Kolthoff and Furman (8), was determined and calculated as fructose from the tables of Schoorl (8). The value for the aldose sugars was obtained by subtracting the percentage of fructose from the percentage of total reducing sugars. The total sugar content was determined after inversion with hydrochloric acid at room temperature and expressed as invert sugar. The non-reducing sugars were calculated by subtracting the percentage of reducing sugars from the percentage of total sugars.

A sample of sugar-free material was hydrolyzed with boiling hydrochloric acid for the determination of polysaccharides. The reducing power of the hydrolysate was then determined and expressed as percentage of anhydrous dextrose.

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[4]Acknowledgment is made to Messrs. H. V. Jordan, J. H. Hunter, H. A. Nelson, and P. M. Jenkins for the care of the plats and assistance in the collection of the samples.

[5]N-P_2O_5-K_2O; total equalled 15%. One-half of the nitrogen was derived from sulfate of ammonia and one-half from nitrate of soda; the P_2O_5 was from 18% superphosphate; and the potash was derived from sulfate of potash.

The total for carbohydrates was obtained by the addition of the percentage concentrations of the individual carbohydrate fractions.

All analytical results were expressed as percentage concentrations in fresh plant material.

ELECTRODIALYZABLE COMPONENTS

The dialysates obtained by the precedure previously described (2, 11) were adjusted to definite volumes, usually 1,000 cc, and suitable aliquots removed for analysis.

Equal aliquots of cathode and anode solutions, usually 50 cc, were combined and hydrolyzed to obtain the "ammonium plus amide" nitrogen. The ammonia was removed by aeration, and determined by titration.

Portions of anolyte and catholyte (50 cc each) were combined, and concentrated to less than 10 cc for the amino-nitrogen determination. The solution was then diluted to exactly 10 cc, and 2 cc aliquots were transferred to a Van Slyke micro-apparatus for analysis. The results were expressed as percentages of alpha-amino nitrogen.

Phosphotungstic acid was used to precipitate the basic nitrogen from a 200-cc aliquot of cathode solution after concentrating to about 50 cc. The nitrogen in the precipitate was determined by a Kjeldahl analysis.

The nitrogen in 50 cc of the cathode dialysate was determined by the Kjeldahl method to obtain the total cathode nitrogen.

The nitrogen in 50- to 100-cc aliquots of anode dialysate was determined by the Kjeldahl method modified to include nitrates. This is called total anode nitrogen.

Interfering substances were removed from an appropriate aliquot of the anolyte (5 to 20 cc) by means of silver sulfate and calcium oxide, and the content of nitrate nitrogen determined colorimetrically.

A 10-cc aliquot of the anode portion was diluted (usually to 250 cc) and 50 cc of this solution analyzed colorimetrically for phosphates according to the method of Truog and Meyer (13).

The residue from the central chamber was dried to constant weight at 100° C and analyzed for nitrogen and phosphorus. The nitrogen was determined by the Kjeldahl method. A 1-gram sample of the residue was digested according to the method of Gerritz (6), and the phosphorus content determined colorimetrically.

Analyses of the residue after dialysis are expressed as percentage of dialyzed material dried at 65° to 70° C.

RESULTS OF THE EXPERIMENT

CARBOHYDRATES

The carbohydrate fractions of the bark and inner portions of the roots of the cotton plants at different stages of growth from fertilized and unfertilized plats are given in Table 1. The concentrations of total reducing sugars, aldose sugars, and ketose sugars in the roots of plants from unfertilized plats are shown graphically in Fig. 1, B and D, and total sugars, polysaccharides, and total carbohydrates in Fig. 1, A and C. The seasonal trends of the data for fertilized and unfertilized plants are essentially the same so the discussion is confined principally to data from unfertilized plants.

The total amount of simple sugars is considerably greater in the bark than in the inner portion of the root. The range in concentration

is from about 0.5 to 1.1% in the bark and from 0.2 to 0.4% in the stele. The average concentration of aldose sugar in the bark is 0.40% and of ketose 0.45%. Although the difference in the average concentrations of aldose and ketose sugars is not particularly outstanding, that of ketose sugars fluctuates markedly during the season, while the change in the concentration of aldose sugars is gradual. In general, the ketose content of the bark is high when that of aldose is low,

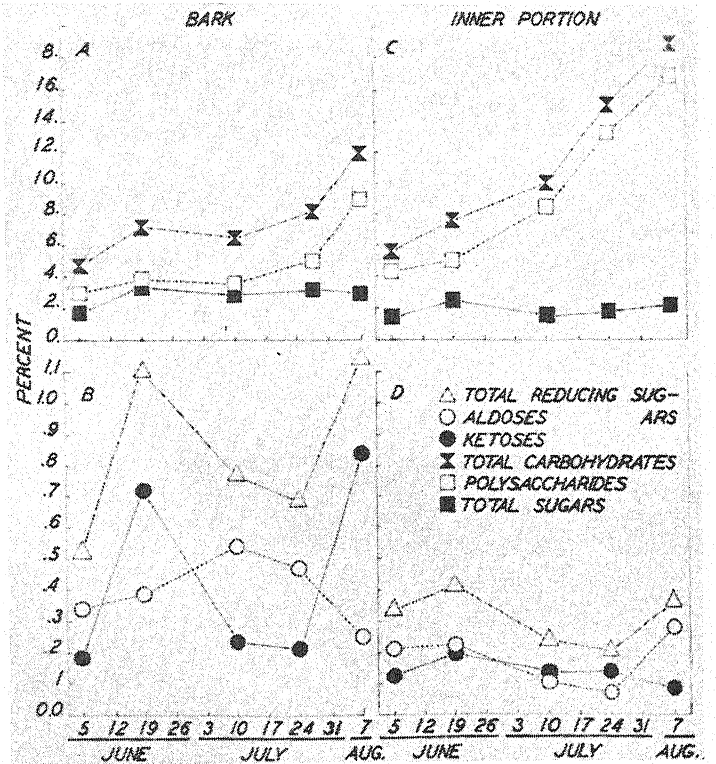

FIG. 1.—Carbohydrate components of the bark and inner portion of roots of cotton plants grown on Wilson clay loam. A and C show total carbohydrates, polysaccharides, and total sugars. B and D, total reducing sugars, aldoses, and ketoses.

and vice versa. The average aldose-sugar content of the inner portion is greater than that of the ketose; the concentrations are 0.18 and 0.13%, respectively.

The concentrations of polysaccharides and total sugars in the bark do not vary greatly until after July 10 and then an increase in the polysaccharide fraction is evident. The stele shows a considerably larger content of polysaccharides than of sugars, even at the early dates of sampling. The polysaccharide content increases rapidly after June 19. The amount of total carbohydrates in the inner portion

TABLE 1.—*Some carbohydrate fractions of the bark and inner portion of the roots of cotton plants at different stages of growth produced on Wilson clay loam soil with varying fertilizer treatment.**

Date of sampling, 1936	Treatment	Sugars					Poly-saccharides %	Total carbo-hydrates %	Weight of root part from 1 plant, grams
		Aldose %	Ketose %	Total reducing %	Non-reducing %	Total %			
				Bark of Root					
June 5	0–15–0	0.47	0.15	0.62	1.29	1.91	2.80	4.71	—
June 19		0.66	0.82	1.48	2.17	3.65	3.19	6.84	2.21
July 10		0.74	0.40	1.14	1.42	2.56	4.14	6.70	5.78
July 24		0.56	0.20	0.76	2.11	2.87	4.66	7.53	8.58
Aug. 7		0.45	0.65	1.10	1.84	2.94	8.66	11.60	10.76
Average		0.58	0.44	1.02	1.77	2.79	4.69	7.48	6.83
				Inner Portion of Root					
June 5	—	0.14	0.16	0.30	1.09	1.39	4.52	5.91	—
June 19		0.25	0.19	0.44	1.94	2.38	6.11	8.49	2.13
July 10		0.12	0.14	0.26	1.33	1.59	9.48	11.07	4.82
July 24		0.14	0.13	0.27	1.50	1.77	12.27	14.04	7.14
Aug. 7		0.27	0.16	0.43	1.62	2.05	16.53	18.58	10.76
Average		0.18	0.16	0.34	1.50	1.84	9.78	11.62	6.21
				Bark of Root					
June 5	3–9–3	0.78	0.44	1.22	0.54	1.76	2.75	4.51	—
June 19		0.54	0.75	1.29	2.13	3.42	3.64	7.06	3.16
July 10		0.57	0.27	0.84	1.75	2.59	3.53	6.12	7.78
July 24		0.61	0.23	0.84	2.05	2.89	4.25	7.14	11.07
Aug. 7		0.15	1.23	1.38	1.83	3.21	7.96	11.17	10.80
Average		0.53	0.58	1.11	1.66	2.77	4.43	7.20	8.20

				Inner Portion of Root					
June 5	—	0.15	0.17	0.32	0.97	1.29	4.41	5.70	—
June 19		0.30	0.13	0.43	1.62	2.05	6.48	8.53	3.28
July 10		0.12	0.15	0.27	1.14	1.41	9.57	10.98	6.40
July 24		0.11	0.18	0.29	1.27	1.56	12.22	13.78	10.39
Aug. 7		0.17	0.15	0.32	1.56	1.88	14.88	16.76	11.45
Average		0.17	0.16	0.33	1.31	1.64	9.51	11.15	7.88
				Bark of Root					
June 5	9–3–3	0.62	0.27	0.89	0.85	1.74	2.82	4.56	—
June 19		0.61	0.73	1.34	2.27	3.61	3.66	7.27	2.56
July 10		0.51	0.34	0.85	1.73	2.58	3.50	6.08	6.82
July 24		0.53	0.22	0.75	2.27	3.02	4.44	7.46	8.82
Aug. 7		0.12	1.00	1.12	2.26	3.38	7.46	10.84	15.02
Average		0.48	0.51	0.99	1.88	2.87	4.38	7.24	8.31
				Inner Portion of Root					
June 5	—	0.19	0.15	0.34	0.93	1.27	4.55	5.82	—
June 19		0.26	0.19	0.45	1.79	2.24	5.57	7.81	2.79
July 10		0.12	0.12	0.24	1.10	1.34	7.76	9.10	6.20
July 24		0.09	0.13	0.22	1.38	1.60	11.86	13.46	7.30
Aug. 7		0.24	0.14	0.38	1.65	2.03	14.91	16.94	16.30
Average		0.18	0.15	0.33	1.37	1.70	8.93	10.63	8.15
				Bark of Root					
June 5	15–0–0	0.54	0.30	0.84	0.93	1.77	3.00	4.77	—
June 19		0.52	0.63	1.15	2.26	3.41	3.55	6.96	1.29
July 10		0.75	0.27	1.02	1.60	2.62	3.83	6.45	4.80
July 24		0.48	0.17	0.65	2.44	3.09	4.85	7.94	7.50
Aug. 7		0.26	0.86	1.12	2.80	3.92	7.62	11.54	10.60
Average		0.51	0.45	0.96	2.01	2.96	4.57	7.53	6.05

*All data expressed on green weight basis.

TABLE I.—*Concluded.*

Date of sampling, 1936	Treatment	Sugars: Aldose %	Sugars: Ketose %	Sugars: Total reducing %	Sugars: Non-reducing %	Sugars: Total %	Poly-saccharides %	Total carbo-hydrates %	Weight of root part from 1 plant, grams
				Inner Portion of Root					
June 5	—	0.16	0.16	0.32	1.14	1.46	4.40	5.86	—
June 19		0.19	0.15	0.34	2.04	2.38	4.93	7.31	1.29
July 10		0.13	0.10	0.23	1.09	1.32	6.86	8.18	4.34
July 24		0.09	0.09	0.18	1.34	1.52	10.78	12.30	5.63
Aug. 7		0.16	0.12	0.28	1.92	2.20	16.82	19.02	10.67
Average		0.15	0.12	0.27	1.51	1.78	8.76	10.53	5.48
				Bark of Root					
June 5	No fertilizer	0.34	0.18	0.52	1.22	1.74	2.89	4.63	—
June 19		0.38	0.72	1.10	2.25	3.35	3.72	7.07	1.29
July 10		0.54	0.23	0.77	2.00	2.77	3.62	6.39	4.88
July 24		0.47	0.21	0.68	2.38	3.06	4.99	8.05	6.58
Aug. 7		0.25	0.89	1.14	1.71	2.85	8.99	11.84	9.86
Average		0.40	0.45	0.84	1.91	2.75	4.84	7.60	5.65
				Inner Portion of Root					
June 5	—	0.21	0.12	0.33	1.04	1.37	4.30	5.67	—
June 19		0.22	0.19	0.41	2.09	2.50	5.08	7.58	1.24
July 10		0.10	0.13	0.23	1.27	1.50	8.46	9.96	4.12
July 24		0.07	0.13	0.20	1.62	1.82	13.21	15.03	4.80
Aug. 7		0.28	0.08	0.36	1.69	2.05	16.83	18.88	9.18
Average		0.18	0.13	0.31	1.54	1.85	9.58	11.42	4.84

*All data expressed on green weight basis.

of the root is influenced more by the polysaccharide content than by the sugar content, and, except for the early period, is from three to eight times greater than that of the total sugars. The total sugars in the bark during the first half of the season affect markedly the level of the total carbohydrates, but as the season advances the higher concentration of polysaccharides dominates.

There is evidence from the relative amounts of the different forms of carbohydrates in the two root parts that a concentration and activity gradient exist between the bark and stele. Reducing and non-reducing sugars are present in the bark in larger amounts than in the stele, while the converse is true for the more complex carbohydrates.

ELECTRODIALYSIS DATA

The data for the nitrogen fractions of the bark and inner portions of the roots of cotton plants for different growth periods on fertilized and unfertilized soil are given in Table 2. In Fig. 2, A and D, are

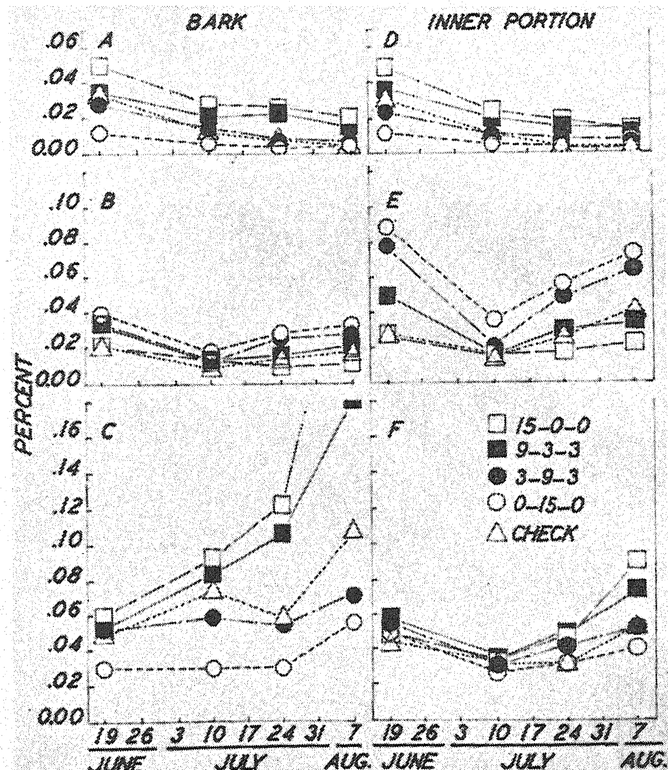

FIG. 2.—Electrodialyzable nitrogenous components of roots of cotton plants produced on Wilson clay loam. A and D show total anode nitrogen, B and E, P_2O_5; and C and F, total cathode nitrogen.

TABLE 2.—*Some electrodialyzable components of the bark and inner portion of the roots of the cotton plant at different stages of growth produced on Wilson clay loam with various fertilizer treatments.**

Date of sampling, 1936	Treatment	Weight per plant, grams	% of total root weight	Amide + ammonium N, %	Amino N, %	Basic N, %	Cathode N, %	Anode N, %	Total anode + cathode N, %	N in residue %	Inorganic phosphate, P_2O_5 %	P_2O_5 in residue %	Residue after dialysis %
						Bark of Root							
June 19....	0–15–0	2.21	50.8	0.011	0.011	0.009	0.030	0.012	0.042	0.155	0.039	0.030	16.8
July 10....		5.78	53.4	0.006	0.009	0.008	0.030	0.006	0.036	0.127	0.018	0.029	17.0
July 24....		8.58	54.6	0.008	0.008	0.006	0.030	0.003	0.033	0.139	0.028	0.033	18.5
Aug. 7.....		10.76	50.0	0.018	0.009	0.010	0.056	0.004	0.060	0.151	0.027	0.042	24.8
Average		6.83	52.2	0.011	0.009	0.008	0.037	0.006	0.043	0.143	0.028	0.034	19.3
						Inner Portion of Root							
June 19....	——	2.13	49.2	0.016	0.015	0.018	0.048	0.012	0.060	0.128	0.089	0.029	23.7
July 10....		4.82	46.6	0.005	0.007	0.009	0.026	0.005	0.031	0.117	0.035	0.034	32.3
July 24....		7.14	45.4	0.008	0.013	0.007	0.031	0.004	0.035	0.124	0.056	0.038	38.6
Aug. 7.....		10.76	50.0	0.009	0.014	0.012	0.040	0.004	0.044	0.129	0.073	0.049	47.1
Average		6.21	47.8	0.010	0.012	0.012	0.036	0.006	0.043	0.125	0.063	0.038	35.4
						Bark of Root							
June 19....	3–9–3	3.16	49.1	0.019	0.016	0.015	0.052	0.028	0.080	0.162	0.034	0.035	16.0
July 10....		7.78	54.9	0.017	0.021	0.019	0.059	0.014	0.073	0.130	0.013	0.029	16.5
July 24....		11.07	51.5	0.018	0.018	0.012	0.054	0.007	0.061	0.146	0.026	0.033	17.9
Aug. 7.....		10.80	48.1	0.022	0.025	0.017	0.071	0.006	0.077	0.185	0.032	0.046	24.2
Average		8.20	50.9	0.019	0.020	0.016	0.059	0.014	0.073	0.156	0.026	0.036	18.7
						Inner Portion of Root							
June 19....	——	3.28	50.9	0.015	0.016	0.015	0.054	0.023	0.077	0.136	0.078	0.030	22.9
July 10....		6.40	45.1	0.006	0.004	0.009	0.031	0.010	0.041	0.125	0.020	0.025	31.4
July 24....		10.39	48.5	0.009	0.009	0.013	0.041	0.007	0.048	0.139	0.049	0.032	37.5
Aug. 7.....		11.45	51.9	0.010	0.020	0.018	0.052	0.006	0.058	0.100	0.064	0.047	43.6
Average		7.88	49.1	0.010	0.012	0.014	0.045	0.012	0.056	0.125	0.053	0.034	33.9

					Bark of Root								
June 19....	9–3–3	2.56	47.8	0.016	0.012	0.015	0.052	0.034	0.086	0.169	0.034	0.026	16.0
July 10....		6.82	52.4	0.027	0.010	0.022	0.084	0.021	0.105	0.143	0.012	0.029	16.3
July 24....		8.82	54.7	0.036	0.047	0.016	0.106	0.023	0.129	0.154	0.016	0.024	17.4
Aug. 7.....		15.02	48.0	0.067	0.077	0.032	0.180	0.015	0.195	0.178	0.019	0.032	22.9
Average		8.31	50.7	0.037	0.037	0.021	0.106	0.023	0.129	0.161	0.020	0.028	18.2
					Inner Portion of Root								
June 19....	——	2.79	52.2	0.013	0.012	0.015	0.057	0.036	0.093	0.142	0.049	0.034	22.4
July 10....		6.20	47.6	0.007	0.003	0.010	0.034	0.020	0.054	0.117	0.016	0.023	29.1
July 24....		7.30	45.3	0.011	0.020	0.016	0.049	0.014	0.063	0.148	0.030	0.039	38.5
Aug. 7.....		16.30	52.0	0.015	0.026	0.027	0.073	0.009	0.082	0.113	0.034	0.042	44.4
Average		8.15	49.3	0.012	0.015	0.017	0.053	0.020	0.073	0.130	0.032	0.035	33.6
					Bark of Root								
June 19....	15–0–0	1.29	50.0	0.030	0.009	0.021	0.060	0.049	0.109	0.153	0.021	0.015	14.6
July 10....		4.80	52.6	0.033	0.024	0.020	0.092	0.027	0.119	0.146	0.010	0.024	16.4
July 24....		7.50	57.1	0.046	0.052	0.017	0.122	0.026	0.148	0.133	0.010	0.030	15.3
Aug. 7.....		10.60	49.9	0.106	0.102	0.052	0.277	0.021	0.298	0.167	0.011	0.033	23.6
Average		6.05	52.4	0.054	0.047	0.028	0.138	0.031	0.169	0.150	0.013	0.026	17.5
					Inner Portion of Root								
June 19....	——	1.29	50.0	0.018	0.020	0.017	0.048	0.048	0.096	0.137	0.027	0.029	19.8
July 10....		4.34	47.4	0.007	0.013	0.009	0.033	0.023	0.056	0.112	0.016	0.019	27.2
July 24....		5.63	42.9	0.011	0.018	0.011	0.047	0.018	0.065	0.138	0.017	0.030	34.9
Aug. 7.....		10.67	50.1	0.024	0.030	0.036	0.090	0.010	0.100	0.156	0.022	0.036	46.3
Average		5.48	47.6	0.015	0.020	0.018	0.055	0.025	0.079	0.136	0.021	0.029	32.1
					Bark of Root								
June 19....	No fertilizer	1.29	51.0	0.017	0.007	0.014	0.049	0.033	0.082	0.165	0.021	0.033	16.0
July 10....		4.88	54.2	0.022	0.029	0.019	0.073	0.013	0.086	0.136	0.009	0.026	17.1
July 24....		6.58	57.9	0.022	0.022	0.010	0.058	0.008	0.066	0.137	0.013	0.025	17.2
Aug. 7.....		9.86	51.8	0.041	0.025	0.016	0.106	0.005	0.111	0.162	0.018	0.036	24.0
Average		5.65	53.7	0.026	0.021	0.015	0.072	0.015	0.086	0.150	0.015	0.030	18.6
					Inner Portion of Root								
June 19....	——	1.24	49.0	0.015	0.016	0.013	0.045	0.030	0.075	0.131	0.027	0.027	20.8
July 10....		4.12	45.8	0.008	0.013	0.009	0.032	0.010	0.042	0.116	0.013	0.022	30.2
July 24....		4.80	42.1	0.012	0.002	0.008	0.031	0.004	0.035	0.121	0.026	0.027	37.9
Aug. 7.....		9.18	48.2	0.011	0.020	0.018	0.052	0.004	0.056	0.159	0.040	0.038	47.3
Average		4.84	46.3	0.012	0.013	0.012	0.040	0.012	0.052	0.132	0.027	0.029	34.1

*Data expressed on green weight basis.

shown graphically the concentrations of anode nitrogen for the bark and inner portion. The general trend of anode nitrogen is downward as the season advances. The concentration in the two root parts is about the same. The high-nitrogen fertilizers have caused an increase in concentration and high-phosphate fertilizers show some tendency to suppress the anode nitrogen as compared with the unfertilized plat.

Fig. 2, C and F, shows the effect of fertilizer on the total cathode nitrogen level of the two root parts. The bark is definitely richer in this nitrogenous fraction than the inner portion of the root and there is an appreciable effect from fertilizers. The trend is upward, in the bark, as the season advances, and the effect of the high-nitrogen fertilizers is pronounced. There is a definite suppression of the cathode nitrogen in the bark by high-phosphate fertilizers, the effect being greater for the 0–15–0 than for the 3–9–3 mixture. The effect of high-nitrogen fertilizers on cathode nitrogen is noticeable in the inner portion of the root, but this is not as marked as in the bark. From the data in Table 2 it is apparent that the cathode fraction is high in amino and basic nitrogen, the relative amounts being in the order given. A rapid increase in the amino nitrogen due to nitrogen fertilizers starts on July 10, while that for basic nitrogen starts 14 days later. An increase in "ammonium plus amide" nitrogen also contributes to this late-season rise. The rise at the last date of sampling for the 0–15–0 treatment is due principally to the "ammonium plus amide" fraction, as the basic-nitrogen fraction shows only a slight increase at that time.

In Fig. 2, B and E, are given the concentrations of dialyzable P_2O_5 in the bark and the inner portion of the root. The effects of the various fertilizers on dialyzable P_2O_5 are more apparent for the inner part of the root than the bark. The 0–15–0 and 3–9–3 fertilizers have definitely increased the concentration over that of the unfertilized samples. The 9–3–3 fertilizer exerted a positive effect only in the young cotton. The lower concentration due to the 15–0–0 ratio at the last two dates of sampling may be due to the prolonged vegetative condition of the plant induced by the added nitrogen.

As seen in Table 2, the average amounts of P_2O_5 remaining in the residues after dialysis do not vary greatly for the two root parts, except in the 9–3–3 sample. In this case the concentration in the stele is considerably greater than that of the bark. Nitrogen alone, 15–0–0, reduced the concentration of residual P_2O_5 in the bark early in the season, but had little effect on the inner portion of the root.

The weights of the bark and stele for the various plants, as given in Table 2, are of interest. The 9–3–3 fertilizer produced a larger average weight of bark and woody material per plant, followed in order by the 3–9–3, 0–15–0, 15–0–0, and check samples.

DISCUSSION

From a detailed study of the transport of carbohydrates in the cotton plant, Mason and Maskell (9, 10) have shown that translocation of sugars takes place through the bark. The data given in this paper, showing much higher concentrations and greater fluctuations of sugars in the bark than in the inner portion at four dates of

sampling seem to support their conclusions. While the entire root of the cotton plant undoubtedly functions as a storage organ, these differences in concentration of both labile and non-labile carbohydrates suggest that the bark and stele differ somewhat in their individual function. It would seem that the stele acts principally as a storage organ while the bark is primarily concerned with transport during the fruiting period and storage becomes a secondary function.

In addition to being richer in soluble carbohydrates the root bark contains more dialyzable nitrogen than the stele. A study of the data in Tables 1 and 2 and Fig. 2 indicates that the concentrations of the nitrogenous constituents have been affected by fertilizer treatment to a greater extent than have the carbohydrate constituents.

The greater concentrations of organic and inorganic phosphorus in the inner portion of the root than in the bark seem significant as the inner portion is also richer in the more complex carbohydrates. Reference to Table 1 shows that the inner portions of roots fertilized with the high-phosphate fertilizers 0–15–0 and 3–9–3 contained higher concentrations of polysaccharides than did those grown with fertilizers high in nitrogen (15–0–0 and 9–3–3). This indicates a correlation of phosphorus content with the formation of the storage carbohydrates. The high level of polysaccharides for the unfertilized check may be due to a lack of nitrogen for protein formation, and, consequently, a lower utilization of carbohydrates.

SUMMARY

The bark was separated from the stele of roots of cotton plants grown on Wilson clay loam soil under various fertilizer treatments. These two root parts were analyzed for some of the carbohydrate fractions, and for the fractions separable by electrodialysis. Under the conditions of the experiment, covering the period from early square formation to early opening of bolls, it was found that the bark is particularly rich in the labile carbohydrate and dialyzable nitrogenous constituents. The inner portion of the root contained more polysaccharides and dialyzable and non-dialyzable phosphates. The latter constituents increased when phosphates were added to the soil. All nitrogen fractions in the root parts are influenced to some degree by the composition of the fertilizer used. The cathode-nitrogen constituents in the bark are most markedly affected.

The ketose sugars appear to play an important part in the physiology of the cotton plant.

The data secured in these experiments show that an analysis of cotton root parts is a promising line of investigation in studying the effect of fertilizers on the composition of cotton plants at various stages of growth.

LITERATURE CITED

1. Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. Washington, D. C. Ed. 3. 1930.
2. Collins, E. R., and Rigler, N. E. Effect of fertilizers on some nitrogenous and other constituents of the cotton plant as separated by electrodialysis at different stages of growth. Soil Science, 44:217–229. 1937.

3. ERGLE, D. R. Carbohydrate content of cotton plants at different growth periods and the influence of fertilizers. Jour. Amer. Soc. Agron., 28:775–786. 1936.
4. ———, HESSLER, L. E., and ADAMS, J. E. Carbohydrates of the cotton plant under different seasonal conditions and fertilizer treatment. Jour. Amer. Soc. Agron., 30:951–959. 1938.
5. FISHER, R. A. Statistical Methods for Research Workers. Edinburg: Oliver and Boyd. Ed. 4. 1932.
6. GERRITZ, H. W. Digesting biological materials for calcium and phosphorus analysis. Ind. Eng. Chem., Anal. Ed., 7:167–168. 1935.
7. JORDAN, H. V., HUNTER, J. H., and ADAMS, J. E. The relation of fertilizers to the cotton plant produced in the Blackland prairie section of Texas. Jour. Amer. Soc. Agron., 30:254–262. 1938.
8. KOLTHOFF, J. M., and FURMAN, N. H. Volumetric Analysis, Vol. 2. New York: John Wiley and Sons, Inc. 1929.
9. MASON, T. G., and MASKELL, E. J. Studies on the transport of carbohydrates in the cotton plant. I. A study of diurnal variation in the carbohydrates of leaf, bark, and wood, and of the effects of ringing. Ann. Bot., 42:190–253. 1928.
10. ———, ———. Studies on the transport of carbohydrates in the cotton plant. II. The factors determining the rate and the direction of movement of sugars. Ann. Bot., 42:571–636. 1928.
11. RIGLER, N. E., ERGLE, D. R., and ADAMS, J. E. Some nitrogenous and other electrodialyzable constituents of the cotton plant at different stages of growth under differential fertilizer treatment. Soil Sci. Soc. Amer. Proc., 2:367–374. 1937.
12. SCHAFFER, P. A., and HARTMANN, A. F. The iodometric determination of copper and its use in sugar analysis. II. Methods for the determination of reducing sugars in blood, urine, milk and other solutions. Jour. Biol. Chem., 45:365–390. 1921.
13. TRUOG, E., and MEYER, A. H. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Ind. Eng. Chem., Anal. Ed., 1:136–139. 1929.
14. WATKINS, G. M. Cytology of phymatotrichum root rot of cotton seedlings grown in pure culture. Amer. Jour. Bot., 25:118–124. 1938.

NATURAL SUCCESSION OF VEGETATION ON ABANDONED FARM LANDS IN THE ROSEBUD SOIL AREA OF WESTERN NEBRASKA[1]

B. I. JUDD AND M. L. JACKSON[2]

ONE of the most interesting and valuable features of natural grassland vegetation is its ability to re-establish itself after it has been disturbed by close grazing or cultivation. The ecologist has made this process the object of careful botanical investigation (17, 18, 23),[3] and the agronomist has paid particular attention to its relation to grazing management. Abandonment of cultivated land on a large scale in recent years in many Great Plains areas has made the natural revegetation process important in erosion control and restoration of the land to hay production and grazing use.

The purpose of this paper is to present further information on the process of natural succession of vegetation on previously cultivated, abandoned farm lands in a semi-arid region. Comparisons are made to conditions in grazed and undisturbed virgin grasslands. A limited consideration is given to seed viability of some native plants. The data show, in general, the time required to secure a grass vegetative cover of agronomic value, and in addition have an ecologic application to the questions of what is the true climax vegetation of the region and how to judge the age of a succession by the species present. The study has a general application to the Brown and Dark Brown Soil Zones (11, 12) from Texas through the Dakotas where abandonment has followed over extension of cultivated crop acreage, although the species in the succession vary somewhat over this large area.

LOCATION OF THE AREA AND ORIENTATION OF THE STUDY

All observations were made in Kimball County, Nebraska, the geographic location of which is shown in Fig. 1. The elevation is about 5,000 feet; the mean annual rainfall is 16 inches; and the mean annual temperature is 47° F. The U. S. Soil Survey Bulletin (14) describes the physiography, climate, and soils of the county. Jackson, Hayes, and Weldon (7) have given detailed descriptions of chemical and morphological characteristics of the Rosebud and associated soil series of the study area. Judd and Weldon (9) have discussed the changes occurring

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director as Journal Series Paper No. 229. A portion of a thesis submitted to the faculty of the University of Nebraska by the senior author (8) in partial fulfillment of the requirements for the degree of doctor of philosophy. This investigation was supported in part by the Conservation and Survey Division, University of Nebraska, Dr. G. E. Condra, Director. Received for publication February 20, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 556.

in the rate of infiltration of water and in the content of organic matter, nitrogen, and root material in the soil during the process of natural revegetation.

The natural vegetation of the region, according to Weaver and Clements (23) was originally mixed grasses, including such mid-grasses as *Stipa* and *Agropyron*. These species have been reduced in abundance and stature by grazing and periodic drouth, and in some areas have been practically eliminated. The resulting vegetation is a short-grass disturbance climax of buffalo (*Buchloe dactyloides*)[4] and blue grama (*Bouteloua gracilis*) grasses with a sedge (*Carex filifolia*) as an abundant associate. This association in its normal development produces a dense sod, is low growing and carpet-like, and has few forbs except in the more moist years. Shantz has described in detail the individual associations (19, 20).

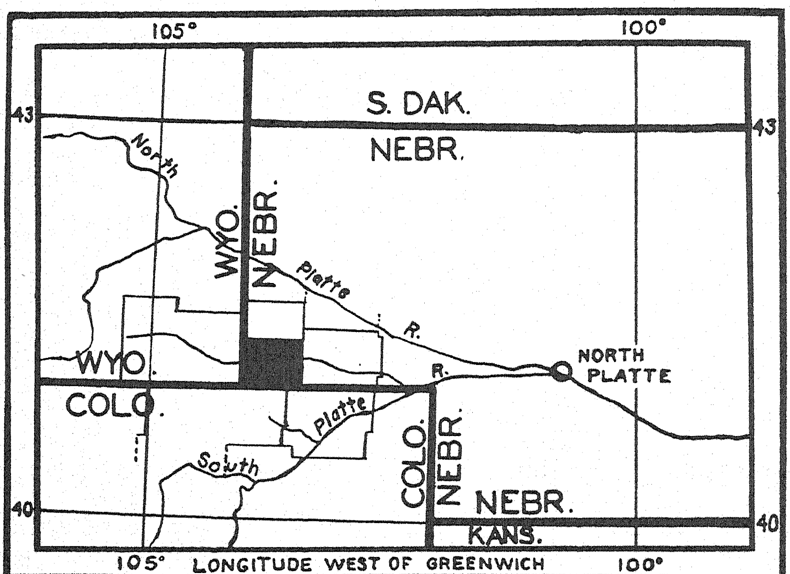

FIG. 1.—Index map showing geographic location of Kimball County, Nebr.

GENERAL PROCEDURE AND METHODS FOR MEASURING ABUNDANCE OF VEGETATION

Period of abandonment.—Abandoned fields were first located in various parts of the county by direct observation and sketched on a base map. Before detailed study of the vegetation was begun, cropping histories on abandoned tracts were secured from the leases and other records of realtors, and in a few instances from farmers and other persons of long residence in the vicinity. The historical data secured for each field studied in detail included the date of abandonment and, in most cases, the date of breaking and the crop sequence for the few years just preceding abandonment. As would be supposed, cropping history could be secured on but a fraction of the total number of abandoned fields. Quadrat studies were carried out only on the fields for which history could be secured.

[4]Acknowledgments for the various species names used in this paper are made in Table 1. All nomenclature is according to the usage of Britton and Brown (2), Hitchcock (6), and (or) Rydberg (16).

Abundance of species.—By *abundance* is meant the proportion of each species present expressed as percentage of total number of stems. The term *frequency* is used to designate the proportion of quadrats in which one or more stems of a given species occurs and is expressed as percentage of total number of quadrats. *Density* of vegetation, as herein used, refers to the average number of stems per quadrat.

The choice of size and number of quadrats was guided chiefly by the experience of other investigators (15, 3, 4, 5, 10, 13), who reported that in general 25 to 50 quadrats are sufficient and that quadrats 0.1 square meter in area give essentially the same results as larger ones. Preliminary trials in the field led to the conclusion that 20 to 40 quadrats 30 cm square were satisfactory from a statistical viewpoint. The data reported in this paper are therefore based on 20 to 40 quadrats 0.09 square meter in area (30 cm square), taken at regular intervals of 2 or 4 rods along a line perpendicular to the principal alternes[5] of vegetation. The number of stems of each species was recorded for each quadrat so that density, frequency (listed species), and abundance interpretations are possible for each species.

In the calculations of these constants, the following procedure was used: (a) The average total number of stems per 0.09 sq. m. quadrat was calculated for each field studied. This is the density of vegetation for a given field. (b) The average number of stems of each species per quadrat was computed for each field. This is density of each species. (c) In case several fields of the same period of abandonment were studied, the density of vegetation and the density of each species were computed for the series of fields from the individual field averages or densities in (a) and (b). (d) The abundance of each species (percentage of the total number of stems) was computed from the average densities in (c). Abundance computed in this manner is, of course, not the same as average abundance computed from abundance of species on each field. Abundance computed as outlined is thought to be more representative of actual hay and pasture values of the fields. (e) The frequency for each species for each field was computed and the average frequency for fields of the same period of abandonment was taken.

Procedure for determining viability of seeds is given with the discussion of viability data.

FACTORS INFLUENCING SUCCESSION OF VEGETATION

Plant succession consists of a series of temporary plant communities, one replacing another as rapidly as a given community alters the environment so as to make it more favorable for the following community than for itself, until climax vegetation finally results. The principal factors controlling the succession are the climate, soil, and past and present land-use.

Precipitation records for the region of study are summarized in Fig. 2. On the average, two-thirds of the mean annual precipitation comes during the five months, April to August. Broad variation is indicated by the data for the wettest and driest years ever recorded. The 48-year annual mean is 16.1 inches. For the first 24 years, the mean is 15.6 inches, and for the last 24 years, 16.6 inches. For the decade 1921–1930, the mean is unusually high, 17.9 inches. During

[5]Alternes of vegetation are local zones or bands of vegetation conditioned by drainage, relief, moisture supply, and other environmental factors which vary regularly and thus give successive and related zones of vegetation.

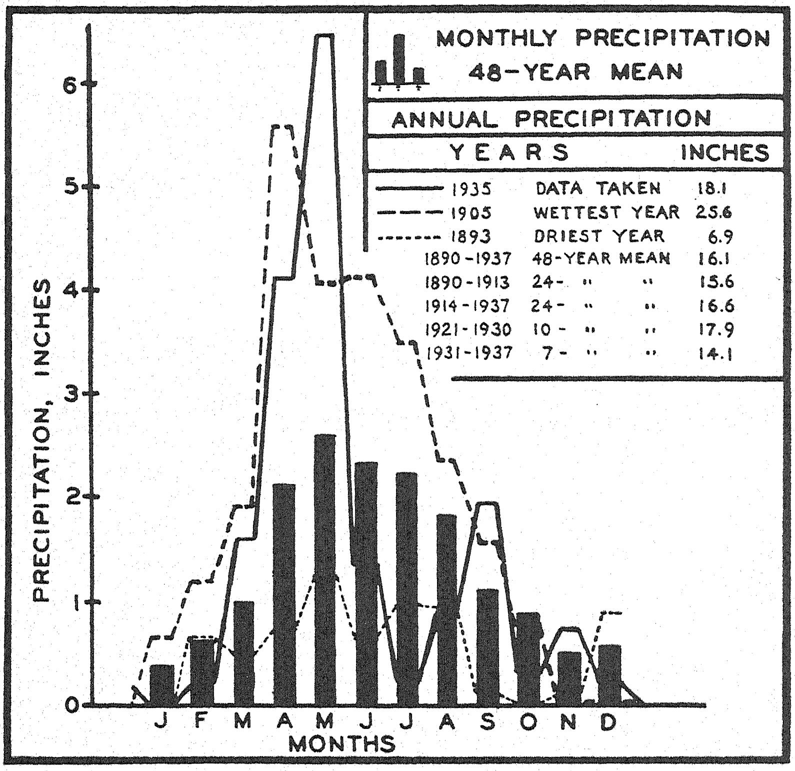

FIG. 2.—Seasonal distribution of precipitation at Kimball, Nebr., and comparison of annual precipitation of selected periods to the mean annual.

this period considerable grassland was broken for wheat growing, and it is not surprising that abandonment has followed during the last seven years with a mean precipitation of only 14.1 inches. The year 1935, during which detailed field observations were made, represents a distinct break in a series of drouth years. A wet spring gave rise to a more dense population for study and an accentuation of differences in the fields of various periods of abandonment. Thus the time of study was opportune for measurements, yet none the less representative of composition, for wide variations from drouth to relatively wet seasons are normal for the region.

SOIL FACTORS

In the region under study any soil character which increases or decreases the amount of water available for plant growth produces a corresponding alteration in vegetation. Jackson, Hayes, and Weldon (7) pointed out some of the relationships between the profile characteristics of the soils of the area, the moisture supply, and the development of vegetation. They show, for example, that stony soils

encourage deeper penetration of water into the soil and consequently support a tall bunch-grass type of native vegetation. Weaver (22) has discussed grass-root relations in the normal soils.

Local environmental associations are indicated in Fig. 3 by letters A to E. The marsh types (A) are nearly static and were almost entirely excluded from the field observations. The place of *Agropyron smithii* (western wheat grass) is broad in the succession studies. It predominates in the upland drain bottoms and at the margins of ponds (B) and completely occupies some of the smaller depressions. It appears as a stage in plant succession as will be pointed out later and persists permanently in the uplands on the heavy soils. A belt of annuals (C) persists just outside of the wheat grass alterne around the ponds. *Chenopodium album* (lamb's quarters) and *Sisymbrium*

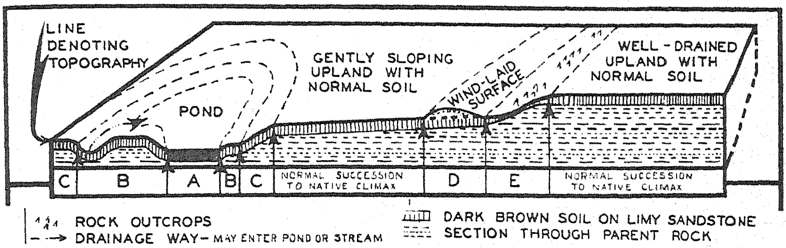

FIG. 3.—The ecologic relationships of vegetation to topography and soil development, Kimball County, Nebr., 1935–37. A, hydrosere, marsh types, *Jungus* sp.; B, pond margins and drain bottoms, *Agropyron smithii* predominates; C, alternes, mostly forbs, influenced by pond; D, retardation by wind deposition, *Chenopodium album*, *Sisymbrium altissimum*, *Helianthus annuus*, *H. petiolaris*; and E, native relicts condition rapid succession to sub-climax and post-climax.

altissimum (tumbling mustard) are the chief species. Periodic inundation combined with wind deposition favors the annuals and disfavors further progress in the succession. Beyond this alterne are encountered the areas of true succession, located on the gently sloping uplands with normal soils. It is here that the quadrat data were taken.

Two other local plant associations were frequently encountered and had to be avoided in the study of true succession. Deep wind deposits (D) check grass vegetation and favor *Chenopodium album*, *Sisymbrium altissimum*, *Helianthus annuus* (common sunflower), and *H. petiolaris* (prairie sunflower), plants whose seeds are laid with the wind deposits. Which of these species dominates depends on local circumstances. Areas of shallow stony soils (E) were usually poorly cultivated; native relicts persisted and rapidly restored a postclimax of mixed short and tall grasses. Besides the principal species, *Buchloe dactyloides* (buffalo grass), *Bouteloua gracilis* (blue grama grass), and *Carex filifolia* (blackroot), four taller species were abundant, namely, *Stipa comata* (western needle grass), *Aristida longiseta* (red three-awn), *Andropogon scoparius* (little bluestem), and *Bouteloua curtipendula* (side-oats grama grass). The usual forb associates of the short grassland were present.

Where native species are completely killed, gravelly knolls have considerable *Boebera papposa* (fetid marigold) and *Plantago purshii* (poor Joe). Emphasis is placed on the abnormality of such areas in natural succession and a maximum exclusion of them from quadrat measurements. This is not as readily accomplished as the idealized diagram, Fig. 3, would indicate. Consequently, small amounts of some of these species seem to be out of place in the data.

PAST AND PRESENT LAND-USE FACTORS

Soil management during the period of cultivation exerts some influence on early stages of succession. Of first importance is the length of time of cultivation. Closely related to this are the thoroughness of cultivation and intermittent use as compared to continuous use. The amount of tillage varies with the type of crop grown. These influences are related to the degree of killing out of the grasses. Once the grass-roots are dead, there is little additional effect. The last crop grown before abandonment influences the first two or three years of succession because plants differ in their ability to withstand the cutting action of blowing sand on previously cultivated land, whereas this adaptation is not significant on a stubble field.

Present use of abandoned land is ordinarily nonintensive or negligible, and possible exceptions must be allowed for in the study of succession. Under close grazing, short grass may never be attained. The presence of recently abandoned land near an older tract may result in wind deposition and retardation of plant growth. The climatic factor, drouth, in this way becomes more important in succession than in climax. Observations in the study area in 1938 revealed *Bouteloua gracilis* persisting as a perfect stand in a native area blanketed by more than an inch of wind-blown materials. *Salsola pestifer* (Russian thistle) plants from 3 to 5 inches high protected the grasses, while shifting sand in adjacent abandoned fallow fields prevented all vegetative growth.

TIME-VARIATION IN SPECIES COMPOSITION ON ABANDONED LAND

Field investigation entailed quadrat measurements on a large number of tracts, but detailed presentation of data for individual tracts is not required for the purposes of this paper. Data from 19 abandoned fields and 3 native areas are summarized in Table 1. Special quadrat studies were made on several other fields, and observations were extended to tracts distributed throughout the county.

ABUNDANCE AND FREQUENCY OF SPECIES

The species are listed in Table 1 in the sequence of their appearance in the succession in appreciable quantities. Abundance and frequency for various years are recorded. The fundamental relationships of the successional species and plant groups, as based on extensive field observations and representative quadrat data, are shown in diagram form in Figs. 4, 5, and 6. Only the major or keynote species for each year will be mentioned in the discussion; the positions and relative

importance of other species are readily found by reference to Table 1. The following eight summary points correspond to eight periods of abandonment; it is clear, however, that weather variations may cause incidental shifts in the rate of entrance and disappearance of a given species. The trends have been verified by observations over

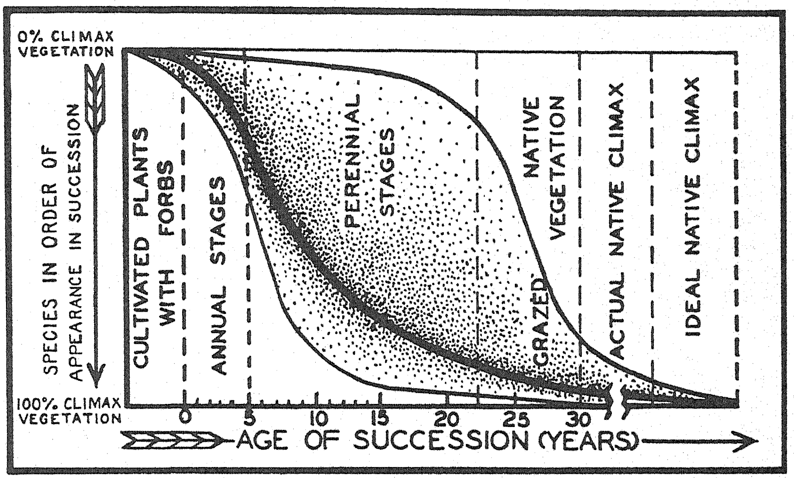

FIG. 4.—Schematic representation of the variety of species and successional stages of vegetation growing on abandoned land shown in relation to grazed native and native climax associations. The data of Table 1 are correlated in this diagram. Height of shaded area indicates variety of vegetation and heavy curve shows trend of predominating species.

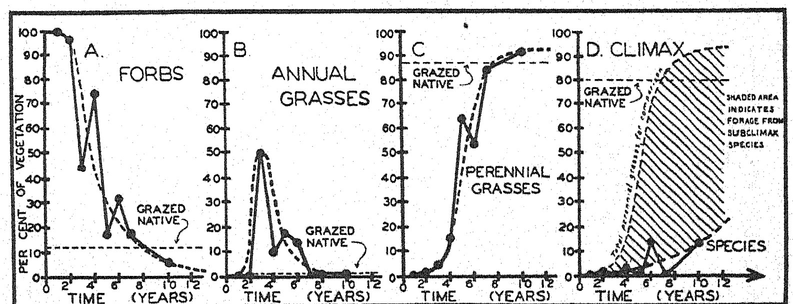

FIG. 5.—Time-variation in the composition of successional vegetation on abandoned land compared to grazed native vegetation. Data expressed as percentages of total number of stems, from Table 2.

broader areas and during a longer time than are represented in the tabulated data.

During the first year, the annual forbs, *Amaranthus retroflexus* (pigweed), *Salsola pestifer*, and *Chenopodium album*, predominate completely. In an individual field, one or the other of these may form 80% or more of total stems. The frequency data show all three species

TABLE 1.—*Abundance and frequency of important species* growing in fields abandoned for periods of time varying from 1 to 10 years or more in comparison to those in native grassland in Kimball County, Nebr., 1935.†*

Species	1 yr., av. 2 fields		2 yrs.,	3 yrs., av. 6 fields		4 yrs., av. 6 fields		5 yrs.,		6 yrs.,		7 yrs.,	10 or more years		Native grass-land, av. 3 fields	
	A	F	A	A	F	A	F	A	F	A	F	A	A	F	A	F
Amaranthus retroflexus L.	**15**	71		3	21	2	16			t	8		t	5	t	1
Salsola pestifer A. Nels.	**36**	100	3	2	40	11	67	1	29	8	58	t			1	21
Chenopodium album L.	**38**	94	**54**	5	68	11	73	4	74	8	70	1	t	10	t	21
Salvia lanceolata Willd.	t‡	4		t	4	1	7								t	1
Setaria viridis (L.) Beauv.	t	4		t	1	1	10									
Anogra coronopifolia (T. & G.) Britton	1	8		t	3	1	11	t	6	t	2				t	5
Sisymbrium altissimum L.	1	13	1	1	21	4	42	t	24	t	25				t	1
Helianthus petiolaris Nutt.	3	25	4	1	13	3	28	t	12	t	2	t	1	45	t	8
Polygonum convolvulus (L.) Dum.	1	17		1	12	1	12			t	4					
Lygodesmia juncea (Pursh.) D. Don.	2	20	3	t	20	1	29	t	15	1	30		t	10	t	1
Polygonum aviculare L.	t	9	3	3	29	1	10	t	9	1	19	t	t	10	t	3
Plantago purshii R. & S.	1	4	**17**	3	18	11	33	4	35	1	13	4	2	40	7	57
Gaura coccinea Nutt.			2	t	1	t	1			t	2					
Lactuca virosa L.			3	t	1											
Lepidium densiflorum Schrad.			3	4	47	6	38	t	21	1	23	t	t	5	1	43
Lappula occidentalis (S. Wats.) Greene			3	9	67	**13**	51	5	44	6	72	1			t	4
Stipa comata Trin. and Rupr.			2	t	1	3	6	**42**	79	t	2	4			1	7
Astragalus gracilis Nutt.				t	2	t	2									
Bromus tectorum L.				**50**	60	8	23	7	53	14	51	t				
Grindelia squarrosa (Pursh.) Dunal	t	4		9	63	4	27	t	3	1	15	3	t	20	1	18

Agropyron smithii Rydb.				4	*18*	6	*18*	**16**	*41*	**35**	*70*	5	1	*10*	2	*43*
Chamaesyce sp. S. F. Gray				t	*1*	1	*8*			t	*2*	t				
Bromus commutatus Schrad.				t	*6*	2	*7*	8	*38*							
Sphaeralcea coccinea (Nutt.) Rydb.	t	4		t	*12*	1	*9*	1	*21*	2	*36*	2	t	*10*	1	*33*
Festuca octoflora Walt.				t	*6*	t	*2*	3	*24*				1	*15*	1	*26*
Helianthus annuus L.				t	*1*							1				
Artemisia frigida Willd.			t	2	*16*	1	*8*	t	*9*	t	*9*	3	2	*25*	1	*23*
Sporobolus cryptandrus (Torr.) A. Gray				t	*1*	1	*4*	t	*3*			1	7	*60*	t	*2*
Schedonnardus paniculatus (Nutt.) Trel.				t	*1*	5	*10*	2	*3*	5	*17*	**74**	3	*20*		
Ambrosia elatior L.				t	*1*	1	*9*	t	*3*				1	*40*	t	*6*
Sitanion hystrix (Nutt.) J. G. Smith				t	*1*	t	*1*	3	*15*			t	t	*5*		
Boebera papposa (Vent.) Rydb.						t	*1*					2				
Aristida longiseta Steud.						t	*1*			t	*2*		**66**	*95*	4	*15*
Polygonum erectum L.						t	*1*			1	*11*					
Juncus sp. L.										2	*4*					
Carex filifolia Nutt.										14	*6*				5	*51*
Buchloe dactyloides (Nutt.) Engelm.				t	*1*	1	*6*						4	*5*	**23**	*33*
Bouteloua gracilis (H. B. K.) Lag.								t	*3*				10	*10*	**52**	*100*
Total number of quadrats measured	25		22§	167		162		34		53		22§	20		72	
Density of Vegetation (Av. stems per quadrat)	19		44	90		54		110		65		149	148		133	

*Composing 1% or more of the vegetation in at least one field or average of fields.

†Data expressed as abundance (A) (% of total stems), frequency (F) (% of total quadrats in which the species occurred), and as density of vegetation (average number of stems per quadrat of 0.09 sq. m. area).

‡Trace; less than 0.5%.

§Two quadrats of 1.0 sq. m. each, equivalent to 22 quadrats of 0.09 sq. m. each.

Species occurring in one or more fields only as traces are as follows: (1) Abandoned and native fields: *Astragalus mollissimus* Torr., *Camelina sativa* (L.) Crantz, *Eriogonum alatum* Torr., *Opuntia* sp. Hill, *Pentstemon albidus* Nutt., *Psoralea lanceolata* Pursh., *Sideranthus spinulosus* (Nutt.) Sweet; (2) Abandoned fields only: *Allionia linearis* Pursh., *Arenaria hookeri* Nutt., *Cirsium arvense* L. Scop., *Lactuca scariola* L., *Leptilon canadense* (L.) Britton, *Macrocalyx nyctelea* L., *Oryzopsis hymenoides* (Roem. and Schult.) Ricker., *Panicum capillare* L., *Solidago mollis* Bartl., *Tragopogon pratensis* L.; (3) Native fields only: *Gutierrezia sarothrae* (Pursh.) Britton and Rusby, *Lappula lappula* L.

to occur in nearly every quadrat. A few other species appear in small amounts. Volunteer rye and other field crops are not uncommon.

In the second year, all three may persist, but *C. album* persists the most. *Plantago purshii* is the outstanding introduction. Minor species are more numerous.

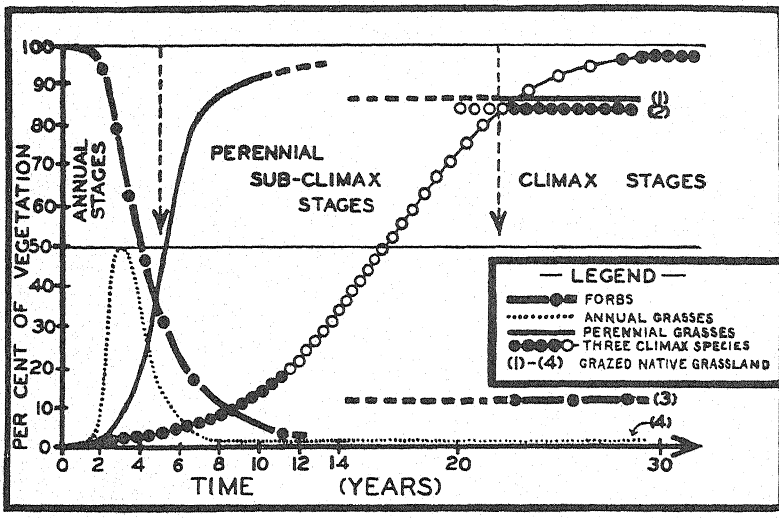

FIG. 6.—Trends in the time-variation of four vegetal classes compared to the composition of grazed native and native climax associations. The trends are taken from Fig. 5 and form the basis of defining the broad stages in this succession.

In the third year, the whole field becomes covered with the annual grass *Bromus tectorum* (downy brome); it forms a stand as complete and uniform as a cultivated crop. An annual forb *Lappula occidentalis* (stickseed) is important but is conspicuous only on gravelly knolls where *B. tectorum* is less well adapted. A host of different species occurs, representative of all stages of the succession except the very last. The third year is still much influenced by the last crop grown before abandonment. The density of *B. tectorum* was found to vary considerably in adjacent fields, being greater on stubble than on previously tilled fields. Little effect of the crop last grown is noticed after the third year.

In the fourth year, *B. tectorum* loses its foothold and *L. occidentalis* increases to greatest abundance. To an even greater degree than before, species from all stages of the succession are represented. The frequency column shows few species present in over half the quadrats: this means the cover is spotted rather than uniform. *Agropyron smithii* is making a small but significant beginning; in the field it appears as scattered patches 5 to 10 feet in diameter.

The most significant change at five years is the marked increase in *A. smithii*. It occurs in nearly half the quadrats and forms one-sixth of the stems. *Stipa comata* appears in more than normal amounts in

the field in which these data were taken. This irregularity is taken into account later in this paper.in establishing trends.

The sixth year is the year for best development of *A. smithii*; the values 35 and 70 for abundance and frequency are thought to be minimum rather than average for this wheat grass stage. *Carex filifolia* appears for the first time in substantial amounts. This is the last year *B. tectorum* is of any consequence.

Schedonnardus paniculatus (wild crabgrass) makes a good growth on the seven-year tract. The data are based on a single field and it is believed that on average fields this species does not replace *A. smithii* to this extent.

A field of 10 or 15 years abandonment showed abundant growth of *Aristida longiseta* and 14% of *Bouteloua gracilis* and *Buchloe dactyloides*. Small amounts of species from all stages still persist. This field of 20 or 30 acres has been permanently removed from cultivation and is available for observations of further changes. It is located in a square mile of native vegetation. Besides the small quadrat measurements reported herein, two permanent quadrats 1 meter square have been established. These were mapped in 1935 and 1938 and will be periodically mapped for one or more decades.

In grazed native grassland, the three most abundant species form four-fifths of the vegetation. *Bouteloua gracilis* occurs in every quadrat; *Buchloe dactyloides* constitute one-fourth of the stems. Species from all stages of the succession occur in small amounts, and frequencies indicate a fairly wide distribution of them. *Plantago purshii* occurs in 57% of the quadrats and forms 7% of the vegetation. This is in agreement with the usual observations in grazed native grassland.

The density of vegetation (reported at the bottom of Table 1) increased from 19 in the first year to nearly 150 in the older fields. The uniform increase is interrupted by the rapid increases of *B. tectorum* in the third year and *A. smithii* in the sixth. An average density of 133 was found on grazed native areas.

The highest values for abundance in Table 1 form a rough line of regression from left to right in the table. The data are further projected, for purposes of illustration, in Figure 4. Annuals begin before abandonment and predominate for four or five years, after which perennials are the more important. The variety of species in a given year is indicated by the height of the shaded area. The diagram emphasizes the early entrance of nearly all the species of the whole succession and their persistence even into moderately grazed native vegetation. Grazing the native vegetation apparently results in increasing the variety of vegetation more or less in proportion to the height of the shaded area in Fig. 4. Climax vegetation has few species surviving from the early successional stages and it is supposed the climax vegetation as modified by moderate grazing would consist largely of the three dominant species.

ABUNDANCE OF PLANT GROUPS

Table 2 shows the abundance of forbs, annual grasses, perennial grasses, and principal climax species calculated by combining abun-

dance of species of Table 1. These data are plotted in Fig. 5. In 5A the drop in forbs at three years is occasioned by the abrupt displacement by annual grasses shown in 5B. The second drop in forbs (5A) at five years is a complement of the sharp increase in perennial grasses (5C), occasioned, as has been pointed out, by an abnormal amount of *Stipa comata* in the fifth-year field. These irregularities are readily eliminated by construction of the broken lines showing trends. These lines showing main trends indicate that the changes in abundance of forbs and perennial grasses are rapid for four to eight years. At 10 years, forbs are less abundant and perennial grasses more abundant than in grazed native areas. Further, the annual grasses come in, flourish, and leave almost completely between the second and the seventh year of succession. The principal species is *B. tectorum*; common also are *B. commutatus* (hairy chess), *Panicum capillare* (witchgrass), and *Setaria viridis* (green foxtail); *Festuca octoflora* (six-weeks fescue) is more common during and after the fifth year. Figure 5D illustrates the slowness and irregularity with which the three principal climax species enter during the first 10 years. The comparison to total perennial grasses emphasizes the rapid rise in forage value of land after the fourth year of abandonment.

TABLE 2.—*Abundance* of various classes of vegetation growing on farm lands abandoned from 1 to 10 years or more, Kimball County, Nebr., 1935–37.*

Time abandoned, years	No. of fields used for average	Forbs %	Annual grasses %	Perennial grasses %	Total† %	Principal climax species,‡ %
1	2	100	0	0	100	0
2	1	98	0	2	100	2
3	6	44	50	5	99	0
4	6	75	10	16	101	4
5	1	18	18	64	100	0
6	1	32	14	54	100	14
7	1	17	0	84	101	0
10 or more	1	7	1	92	100	14
Native (grazed)	3	12	1	87	100	80

*Percentage of total number of stems.
†Percentage of traces added in to reduce accumulative error.
‡*Buchloe dactyloides, Bouteloua gracilis, Carex filifolia.*

In Fig. 6, the trends in the four plant groups (Fig. 5) are combined and projected through a greater period of time on the basis of known points. Again, the corresponding abundance found in grazed native grassland is shown for comparison. This summary graph shows that the perennials become more important than the forbs at about five years and that the annual grasses are sharply declining from their maximum. Subsequent to this time perennial grasses flourish, with only a few perennial forbs in the wetter years. The succession of perennial grasses, involving a gradual replacement of taller grasses by shorter ones is beyond the year-to-year abandonment periods studied in this investigation. Certain observations throw significant light on the replacement processes, and these are now summarized, first with regard to plant-competition for water and then as to the relationships of a number of the perennials to climax vegetation.

PLANT-COMPETITION FOR WATER

At the outset of the succession, the land is partially or wholly without cover, so that water is accumulated in the soil. Were the climax species seeded in the area, they would flourish and succession would be accelerated. Under natural circumstances, seeds from the ever-present annual forbs are the most rapidly disseminated, and a thin stand of vigorously growing plants results. On fruiting, these first year plants give rise to a thick stand the following season. So thick is this stand that the plants compete strongly for the already dwindling water supply and mortality becomes high. Annual grasses, better able to grow and seed in early season on seasonal precipitation, find opportunity to flourish in the third season. Those perennial grasses having most rapid means of propagation are first to begin replacing the annuals. Their great increase comes in the fifth and sixth years. At this time infiltration of water is more rapid and penetration greater than later in the succession, with the result that deeper rooted species are more favored at this stage than later.[6] *Agropyron smithii* is the best example of the species adapted for replacing the annuals; it tolerates extremes of water supply, spreads rapidly by both seed and rhizomes, and is fairly deep-rooted. In the course of time, the soil becomes more compact and infiltration less rapid. Species having shallow rooting habits in addition to an adaptation to withstand extremes of drouth are able to utilize moisture before it reaches the deeper rooted perennials. In this way, *Bouteloua gracilis*, *Buchloe dactyloides*, and *Carex filifolia* replace species of the *A. smithii* type to a large degree and become dominant, particularly where grazing tends to reduce the abundance of the taller grasses (23).

RELATIONSHIP OF SUCCESSIONAL TO CLIMAX SPECIES

Plant associations with *A. smithii*, *Stipa comata*, *Aristida longiseta*, and *Sporobolus cryptandrus* (sand dropseed) appear often in native areas. The climax vegetation for a broad region can be defined satisfactorily only with reference to zonal soils. Thus *A. smithii* appears normally in the succession but is replaced on medium-textured, well-drained upland soils under moderate grazing conditions. It persists indefinitely in drainage ways, pond margins, and on heavy soils. This species enters most rapidly of the perennials and yields the maximum forage of all stages in the succession. *S. comata* similarly is replaced in the normal succession under grazing but persists on coarse-textured soils. This species appears consistently on nearly all gravelly spots in abandoned fields, and thus appears to be better adapted for such a habitat, although accidental seeding and relicts may be responsible for its re-establishment in some cases. It is not uncommon to find *S. comata* spots in a dense field of *A. smithii*. In coarse-textured soils more than a normal supply of water is available, and this accounts for persistence of this taller species. Homestead cultivated areas abandoned 25 or 30 years showed an appreciable amount of *S. comata* and

[6]Data are far from complete on runoff and moisture penetration in various types of grassland. Weaver and Noll (24) and Judd and Weldon (9) furnish data partially applicable to this point.

other taller species, but the cover was more sparse than climax vegetation and the short grasses predominated. *Aristida longiseta* and *Sporobolus cryptandrus* are probably minor species in the true climax. The former was found abundantly at 10 to 15 years abandonment with moderate grazing.

VIABILITY STUDIES WITH NATIVE SPECIES

Seeds from 24 grasses and 15 legumes were collected in Kimball County, in late summer and fall, 1935. The grass seeds were examined for the presence of caryopses by spreading them out in a single layer over a glass plate illuminated from below.[7] This examination raises the germination percentage, because the empty glumes resembling seeds can be removed. The germination was carried out between moist blotters, placed alternately in two germinators. Seeds were kept at 20° C for 18 hours and at 30° C for 6 hours each day. Four lots of about 100 seeds each were used for each species. Scarification with sandpaper was tried for all the legumes and two of the grasses. The results are reported in Table 3. Scarified legumes gave 32 to 83% germination except one species, *Lathyrus ornatus* (showy vetchling). The grasses gave medium to high viability except for three species. After scarification, *Oryzopsis hymenoides* (Indian ricegrass) and *Sporobolus cryptandrus* still showed low viability. The most striking fact is the high viability for practically all species.

AGRONOMIC APPLICATIONS OF STUDY

Shantz (17, 19, 21) presented various phases of indicator significance of native vegetation when there was still much unbroken native upland. Information on succession aids in interpretation of present use and use-suitability of land in the Plains region today.

PRESENT LAND-USE AND SUCCESSION

In a typical level upland sample area (7), 87% of the land is or has been cultivated, and in 1935, 24% of the land was abandoned.[8] This means that, at least in some periods, three-tenths of the cultivated land is engaged in various stages of natural revegetation. It is of significance, therefore, that after five years of abandonment, high forage yields are possible. From ¾ to 1 ton of hay per acre is cut from the best wheat grass fields.

All the species in the succession have a significance in the production of cover and roots, which are aids in the control of dust storms, floods, and erosion.

LAND USE-SUITABILITY

It is perhaps inevitable that extensive breaking of grassland will occur during years of high rainfall and high prices. Use-suitability of

[7]Method mentioned by Blake (1) and used by the Soil Conservation Service, Lincoln, Nebr.

[8]Data from the office of the County Agricultural Agent indicate a lower proportion of abandoned land in the county as a whole because extensive rough areas have not been cultivated.

TABLE 3.—*Viability of native grass and legume seeds.*

Grass seeds	Germination Unscarified %	Germination Scarified %	Legume seeds	Germination* Scarified %
Agropyron albicans	69	—	*Astragalus adsurgens*	67
Agropyron smithii	95	—	*Astragalus carolinianus*	47
Andropogon scoparius	87	—	*Astragalus crassicarpus*	28
Aristida longiseta	98	—	*Astragalus drummondii*	37
Bouteloua curtipendula	95	—	*Astragalus gracilis*	74
Bouteloua gracilis	94	—	*Astragalus missouriensis*	50
Bouteloua hirsuta	87	—	*Astragalus mollissimus*	63
Bromus commutatus	52	—	*Astragalus shortianus*	83
Bromus tectorum	75	—	*Lathyrus ornatus*	1
Buchloe dactyloides	67	—	*Petalostemum candidum*	76
Calamovifa longifolia	91	—	*Petalostemum purpureum*	71
Elymus canadensis	95	—	*Psoralea esculenta*	74
Festuca octoflora	90	—	*Psoralea hypogea*	42
Koeleria cristata	74	—	*Psoralea lanceolata*	47
Muhlenbergia cuspidata	1	—	*Sophora sericea*	32
Munroa squarrosa	26	—		
Oryzopsis hymenoides	low	10		
Poa pratensis	92	—		
Schedonnardus paniculatus	100	—		
Setaria viridis	43	—		
Sitanion hystrix	88	—		
Sporobolus cryptandrus	low	1		
Stipa comata	59	—		
Stipa viridula	11	—		

*Unscarified seed gave "low" germination.

the land for less intensive enterprises is indicated when the intensive users fail to earn production costs and abandon the land. Grazing use would be gone except for costly reseeding or natural succession. Severe overgrazing likewise does not satisfy the requirements for continued profitable land-use over a long time because of its destructive effect on both successional and climax vegetation.

Use-suitability of land in this area is not limited directly by lack of soil fertility or soil depth. Misuse of land arises chiefly with an overdevelopment of intensive agricultural enterprises in a region of severe climatic limitations—a short frost-free season of 128 days, hail and wind hazard, and recurrent shortage of sufficient water for cultivated crop production. The inevitable abandonment of land which results periodically sets into operation the processes of natural succession of vegetation.

SUMMARY

This investigation deals with the natural succession of vegetation on previously cultivated, abandoned farm lands in an arid region. The plant communities composing the succession are broadly limited by the climatic and soil conditions. The study was confined to the normal soil on the gently undulating upland so that the effect of these factors would be the same for all fields. The cropping system pre-

ceding abandonment influences the successional vegetation during the first three years.

Beyond these three influences, the time-variation in species composition is controlled chiefly by the changing relationships in the plants' competition for water. During the first five years, annual species predominate. Vigorously-growing annual forbs soon use soil moisture stored under bare ground. Annual grasses flourish in the third year and decline rapidly in the fourth to sixth years. Deeper-rooted, more drought-resistant perennials appear to have an advantage in moisture competition at this stage. *Agropyron smithii* leads the perennial grass entrance, beginning in the fourth year and dominating the whole cover in the sixth. At 10 to 15 years nearly all of the cover is composed of the perennial grasses of which 14% is the climax short grasses. Small amounts of species representative of all stages in the succession persist through this intermediate period. The short-grass species take the water as it begins infiltration into the soil, thus placing the deeper-rooted perennials at a disadvantage, and providing for a gradual return of short-grass sod.

Grazing of native grassland allows an influx of most of the successional species. A larger percentage of forbs occurred in grazed native areas than in fields abandoned 10 years or more. This fact and the wide variety of vegetation in intermediate stages indicate that it is not until the latest period in the succession that the annuals and short-lived perennials are crowded out of the cover. The climax short-grass species made up four-fifths of the grazed native population compared to the 14% on the 10-year field.

A high viability of seed was found for all but 3 of the 24 native grasses tested. Similarly, all but 1 of the 15 native legumes showed high viability, provided the seeds were first scarified with sandpaper.

Natural succession of vegetation is important in the Great Plains from an agronomic standpoint in returning abandoned cultivated lands to forage production. After five years, the yield of grass hay often exceeds ¾ ton per acre in moderately wet years.

LITERATURE CITED

1. BLAKE, A. K. Viability and germination of seeds and early life history of prairie plants. Ecol. Monog., 5:405–460. 1935.
2. BRITTON, N. L., and BROWN, A. Illustrated flora of the northern United States and Canada. I, II, III. New York: Scribner's Sons. 1913.
3. HANSON, H. C., BALL, W. S. An application of Raunkiaer's law of frequency to grazing studies. Ecology, 9:467–473. 1928.
4. ————, and LOVE, L. D. Size of list quadrat for use in determining effects of different systems of grazing upon *Agropyron smithii* mixed prairie. Jour. Agr. Res., 41:549–560. 1930.
5. ————. A comparison of methods of botanical analysis of the native prairie in western North Dakota. Jour. Agr. Res., 49:815–842. 1934.
6. HITCHCOCK, A. S. Manual of the grasses of the United States. U. S. Dept. Agr. Misc. Pub. 200. 1935.
7. JACKSON, M. L., HAYES, F. A., and WELDON, M. D. Some chemical and morphological relationships between soil profiles of the Rosebud and associated soil series in southeastern Kimball County, Nebraska. Soil Sci. Soc. Amer. Proc., 2:437–445. 1937.
8. JUDD, B. I. The restoration of grassland conditions in the high plains section of western Nebraska. (Thesis presented to the Univ. of Nebraska. 1936.)

9. JUDD, B. I., and WELDON, M. D. Some changes in the soil during natural succession of vegetation after abandonment in western Nebraska. Jour. Amer. Soc. Agron., 31. 1939.
10. KENOYER, L. A. A study of Raunkiaer's law of frequence. Ecology, 8:341–349. 1927.
11. MARBUT, C. F. Soils of the Great Plains. Ann. Assoc. Amer. Geog., 13:41–66. 1923.
12. ———. Soils of the United States. U. S. D. A. Atlas of Amer. Agr., pt. 3. 1935.
13. MCGINNIES, W. G. The relation between frequency index and abundance as applied to plant populations in a semiarid region. Ecology, 15:263–282. 1934.
14. MEYER, A. H., VEATCH, J. O., TILLMAN, B. W., HAYES, F. A., MORTLOCK, H. C., and COLLETT, C. E. Soil survey of Kimball County, Nebraska. U. S. Dept. Agr. Bur. Soils. 1917.
15. RAUNKIAER, C. Formationsundersøgelse og formationstatistik. Bot. Tidsskr., 30:20–80. 1909.
16. RYDBERG, P. A. Flora of the prairies and plains of central North America. New York: New York Bot. Garden. 1932.
17. SHANTZ, H. L. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. D. A. Bur. Plant Ind. Bul. 201. 1911.
18. ———. Plant succession on abandoned roads in Eastern Colorado. Jour. Ecol., 5:19–42. 1917.
19. ———. The natural vegetation of the Great Plains region. Ann. Assoc. Amer. Geog., 13:81–107. 1923.
20. ———. Natural vegetation: grassland and desert shrub. U. S. D. A. Atlas Amer. Agr. 1924.
21. ———, PIEMEISEL, R. L. Indicator significance of the natural vegetation of the southwestern desert region. Jour. Agr. Res., 28:721–802. 1924.
22. WEAVER, J. E. Root development in the grassland formation. Carnegie Inst. Wash. Pub. 292. 1920.
23. ———, and CLEMENTS, F. E. Plant ecology. New York: McGraw Hill. 1938.
24. ———, and NOLL, W. C. Comparison of run-off and erosion in prairie, pasture, and cultivated land. Univ. Nebr. Conserv. and Surv. Div. Bul. 11. 1935.

EFFECT OF MUTILATION OF WHEAT SEEDS ON GROWTH AND PRODUCTIVITY[1]

W. J. SANDO[2]

WHEN wheat is threshed some of the grains are usually broken. This damage in very dry wheat frequently exceeds 2% and may amount to more than 10%. The value for seeding purposes of the germ end of broken grains is of interest to the farmer.

Obviously, the fragments without embryos are a total loss in seed grain. If, as has often been stated arbitrarily, in the formation of the seed nature supplies food reserves in considerably greater quantities than is necessary to insure a normal development of the seedling up to a stage at which it is capable of independent support, then within limits fragments of grains containing embryos might be expected to produce normal plants. There is evidence, however, that the removal or reduction of the food reserves of the seed results not only in a deleterious effect upon the early growth of the seedling but also in impaired subsequent development.

Extensive experiments have been carried on by various investigators to determine the effects upon the germination of seeds and the subsequent development of the resulting plants when portions of the seed have been removed. These experiments, however, have dealt principally with embryos devoid of endosperm and few have been carried on entirely in the field or continued up to the maturity of the plants.

This article presents the results of field plantings of winter wheat seeds from which different portions of the endosperm were removed, together with additional observations on plantings made in greenhouse flats.

REVIEW OF LITERATURE

Andronescu (1)[3], Blociszewski (4), Bonnet (5), Brown (6), Brown and Morris (7), Dubard and Urbain (10), Sachs (14), Stingl (15), and Van Tieghem (16) found that the endosperm was not indispensable for the germination of the embryo or for the early development of the young plant.

Cronbach (8) found a higher and more rapid germination in half kernels than in whole kernels of wheat.

Delassus (9) and Wollney (17), as quoted by Brown (6), experimenting with kernels of vetch, beans, peas, lupines, and rye having various proportions of the seed attached to the embryo, found the plants produced from whole seeds superior in development.

Although the present study deals with mutilated seed, the possible bearing on the size of seed is obvious. Kiesselbach and Helm (13) carried on experiments to determine the relation of size of seed to yield and reviewed the extensive literature dealing with size of seed. The later work of Arny and Garber (2), Kidd and West (11, 12), and of Bayles (3) is of interest. In general, these investigators report

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication February 20, 1939.
[2]Agronomist.
[3]Figures in parenthesis refer to "Literature Cited", p. 565.

a significant and in many cases a high degree of correlation between size of seed and size of the young plant and usually also a high correlation between size of seed and yield per plant and between size of seed and yield per acre in spaced plantings. When equal quantities of seed per acre rather than equal numbers have been used, no differences in yield have been observed or they have been very small and of no practical importance.

MATERIALS AND METHODS

Uniform, plump kernels of two varieties of winter wheat, Dawson and Nittany, were cut transversely with a razor blade, approximately half the seed being removed from some lots and about two-thirds from the other lots of each variety. The ends containing the germs were then grown in the field at the Arlington Experiment Farm, Arlington, Va. The experiment was carried on in the three years 1933, 1934, and 1935. To determine the possible effect of micro-organisms attacking the exposed ends of the kernels, a portion of the cut kernels were carefully capped with a film of paraffin for comparison with the unparaffined seeds.

Whole and cut kernels were equispaced in 5-foot rows 1 foot apart. At harvest all the plants were pulled, weighed individually after removing the roots, and then threshed. The size and arrangement of the field experiments varied slightly in the different years.

In addition, whole and divided wheat kernels of the spring variety, Baart, were planted in greenhouse flats containing either sterilized or unsterilized soil, to determine further any injurious effect of soil-borne organisms on the cut seeds as well as to observe differences in germination and in the development of the plants at different stages. The flats were 12 inches wide, 24 inches long, and 3.5 inches deep. Three rows each of whole, half, and third kernels were planted to a flat, at the rate of 21 kernels per row.

FIELD EXPERIMENTS

The first experiment consisted of four-row block plantings of whole and half seeds of the Dawson and Nittany varieties. Twenty-five whole or half kernels were equispaced in each row on October 12, 1933. The whole seeds of both varieties showed a decided advantage over the half seeds. As an average for the two varieties the whole seeds produced 25.4% more plants and 50% more grain per plant than the half seeds.

In 1934 a total of 127 5-foot rows were planted, 67 of Dawson and 60 of Nittany. Since the results from the two varieties were similar, the data are combined in Table 1. Twenty-five whole or fragmentary kernels were equispaced in each row. The plantings made in the field on October 13 were as follows: (a) Whole, half, and one-third kernels of Dawson and Nittany in alternate three- or four-row blocks. (b) Whole and half kernels of the same varieties in alternate rows.

In Table 1 a distinct and consistent advantage of whole over half seeds is shown and the half kernels were superior to the one-third kernels in all the treatments.

The half and one-third kernels were slower in germinating and the plants were less vigorous than those from whole seeds. The difference in vigor of seedlings is shown by the percentage of the plants that had reached the two-leaf stage. Half seeds produced a higher percentage

of two-leaf plants than did the plants from one-third seeds and whole seeds produced the highest percentage of two-leaf plants.

TABLE 1.—*Plant development from whole, half, and one-third kernels of Dawson and Nittany winter wheat sown October 13, 1934.*

Portion of seed	No. of rows planted	Germination %	Plant survival %	2-leaf plants on Nov. 3 %	Seeds producing mature plants %	No. of culms per plant	Av. weight per plant	
							Total, grams	Grain, grams
			Grown in Separate 3- or 4-row Blocks					
Whole....	60	87.0	82.7	41.5	72.0	4.7	13.8	3.5
Half......	20	79.1	63.0	11.9	49.8	3.6	9.4	2.2
One-third .	15	59.4	9.0	1.4	5.3	1.6	2.9	0.9
			Grown in Alternate Rows					
Whole....	16	91.2	94.5	45.7	86.2	5.8	16.1	4.4
Half......	16	81.7	62.7	11.6	51.2	3.2	7.6	2.0

In 1935, a total of 77 5-foot rows were planted, 20 of Nittany and 57 of Dawson. Twenty whole or partial kernels were planted equispaced in each row. The plantings were made in the field on October 13 as follows: (a) A single block each of whole, half, and one-third kernels. The blocks consisted of 12 rows of whole kernels, 9 rows of half kernels, and 8 rows of the one-third kernels. (b) Nine single rows each of whole and half kernels planted alternately. (c) Five single rows each of whole, half, and one-third kernels planted alternately. (d) A five-row block of whole seed and a two-row block of paraffined one-third seeds grown adjacent to an eight-row block of paraffined half kernel plantings. Sixteen rows of unparaffined half kernels were included for comparison with the paraffined half kernels.

Because of the similarity of the results of the two varieties, the data were combined and the results are presented in Table 2. A comparison of the data in Table 2 shows with one exception a consistent advantage of the whole seed plantings over the half and one-third seed plantings while the half-seed plantings were superior to those from one-third seeds.

The small differences exhibited between the whole, half, and one-third seeds sown in blocks (Table 2) may be attributed to the unfortunate use in this experiment of a plot of land later found to be somewhat inferior in fertility near the ends. The plantings of the other treatments in this experiment were made in a more fertile soil.

It will be noted that plant survival, culms per plant, weight of plant, and weight of seed per plant from plantings of half kernels with paraffined ends were greater than from plantings of half kernels without paraffined ends. This greater injury suggests the invasion of the seed pieces by organisms through the exposed unparaffined ends. From the germination results it appears that the embryos were not injured by parasitic organisms in the early stages of their development but some injury to the mature plants is indicated.

TABLE 2.—*Plant development from whole, half, and one-third kernels of Dawson and Nittany winter wheat sown October 13, 1935.*

Portion of seed	No. of rows planted	Germination %	Plant survival %	Seeds producing mature plants %	No. of culms per plant	Av. weight per plant: Total, grams	Av. weight per plant: Grain, grams
			Grown in Blocks of Rows				
Whole......	12	89.5	95.3	85.4	4.4	15.1	4.7
Half.......	9	88.3	90.6	80.0	3.9	13.5	4.0
One-third...	8	75.0	70.0	52.5	3.8	12.8	3.7
			Grown in Alternate Rows				
Whole......	9	95.0	96.5	91.7	6.3	23.2	7.4
Half.......	9	86.6	87.6	78.9	3.7	12.1	3.6
			Grown in Alternate Rows				
Whole......	5	94.0	98.9	93.0	7.1	28.4	8.7
Half.......	5	82.0	93.9	77.0	4.8	17.8	5.3
One-third ..	5	47.0	74.6	35.0	2.6	11.8	3.3
			Paraffined Half Kernels Sown Adjacent to Whole and Unparaffined One-third Seeds (Dawson only)				
Whole......	5	86.0	86.0	74.0	7.1	21.6	6.9
Half.......	8	82.5	92.4	76.2	4.9	14.5	4.7
One-third...	2	92.5	83.8	77.5	4.3	13.1	4.0
			Unparaffined Half Kernels of Dawson				
Half.......	16	86.6	89.5	77.5	4.0	13.9	4.1

The average weight of grain per plant from half kernel plantings in three experiments was 33.3%, 46.8%, and 36.5% less, respectively, than from whole kernel plantings and in two experiments the average weight of grain per plant from one-third kernels was 73.9% and 45.8% less, respectively, than that from whole seed.

The results from field plantings of fractional kernels indicate that the seedling is set back so severely in its initial growth that full development rarely occurs.

Some of the reduction in the germination of the fractional portions of seeds planted in the field was due to the weakened condition of the plants which prevented their emergence. Several malformed plants were detected which failed to break through the soil crust.

All of the experiments in the field were conducted under conditions in which some winterkilling was possible. Since the plants produced by half and one-third seeds were less vigorous than those produced by whole seeds, they probably were more susceptible to winter injury. This damage is indicated by the greater mortality of the plants and also by the reduced weight, yield, and number of culms of the plants that survived.

GREENHOUSE EXPERIMENTS

A single flat containing sterilized soil was seeded to three rows each of whole, half, and one-third seeds of the spring variety Baart. The

plants emerged three days after seeding and no injury by parasites was observed.

The plants three days after emergence are shown in Fig. 1. Distinct differences between the plantings may be seen. In general, the

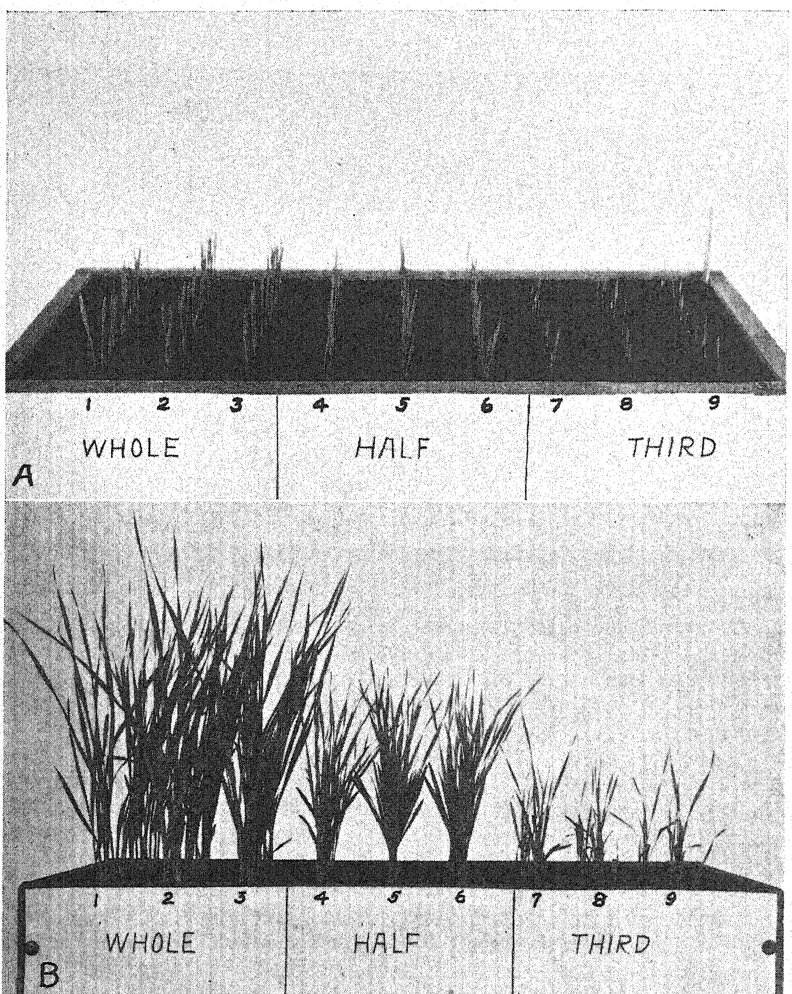

FIG. 1.—Plants from whole, half, and one-third wheat kernels *above*, grown in sterilized soil, 3 days after emergence; *below*, unsterilized soil 13 days after emergence.

plants from the whole seeds appeared very uniform while those from the half seeds were neither as uniform nor as tall as those from the whole seeds. The plants from the one-third seeds were decidedly more nonuniform, more slender, and shorter than those from half

seeds, and showed considerable distortion. The germination percentages of the whole, half, and one-third seeds were 94.4, 96.2, and 66.6, respectively. No plants from the whole seed plantings died after emergence, but the mortality in the half and one-third seed plantings was 1.9% and 11.1%, respectively.

The plants from the various treatments headed two days apart; those from the whole seed headed first and those from the half and one-third seeds followed in order. Measurements of each plant at two-day intervals were made as soon as the plants appeared above the ground. These measurements are illustrated graphically in Fig. 2.

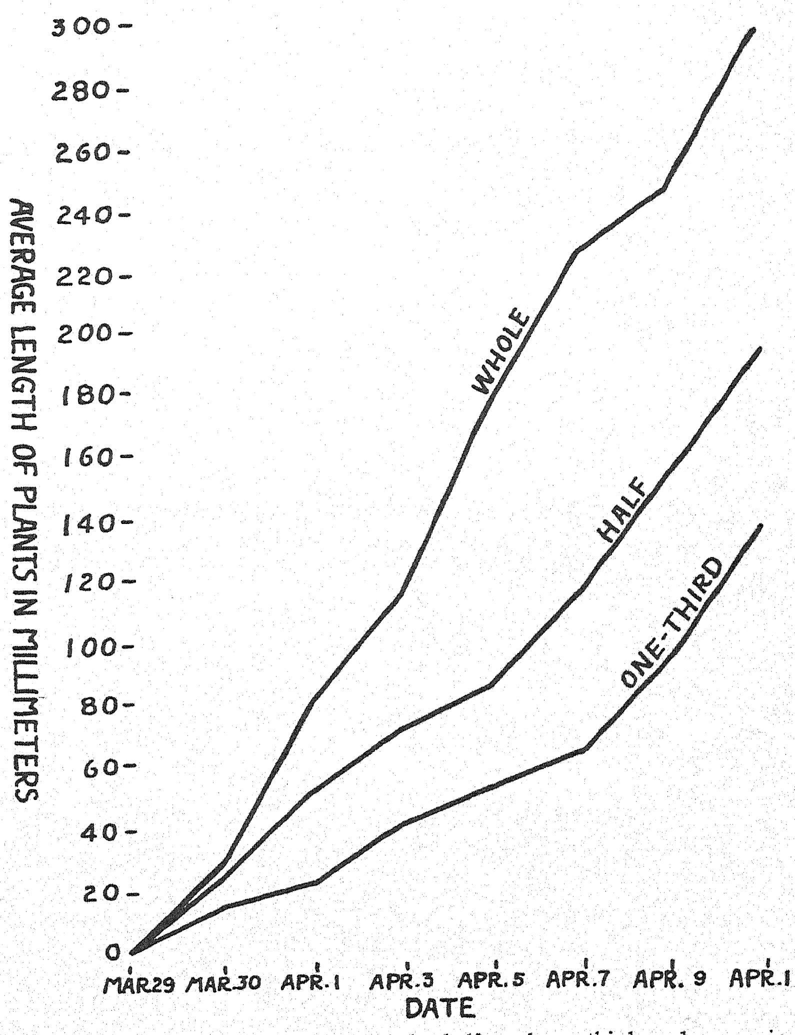

FIG. 2.—Length of plants from whole, half, and one-third seeds sown in sterilized soil.

The growth was greatest in the plants from whole seeds during the period when measurements were made, but this higher growth rate was not maintained to maturity.

A second flat containing unsterilized soil was planted with whole, half, and one-third kernels of the variety Baart. The germination percentage of the whole, half, and one-third seeds was 100, 92, and 74.6, respectively. The mortality of the plants was for the whole, half, and one-third seeds 4.8%, 6.9%, and 29.8%, respectively.

Fig. 1 also shows the plants when 13 days old. In general, the relationships between the various groups are similar to those grown in the sterilized soil. Some plants from one-third seeds in the unsterilized soil, however, showed injury by soil parasites. On March 22, four days after emergence, the average length of the plants grown in unsterilized soil was for the whole, half, and one-third seeds 111.5, 82.2, and 32.5 millimeters, respectively.

Additional data were taken at maturity on the plants referred to above, but the plants were so obviously distorted, owing to close planting, border influence, and the small size of the container (which prevented normal development of the plants), that no reliance could be placed on the measurements.

In the greenhouse the plants were grown in a light, loamy soil that produced no surface crust, but a few plants from the one-third seeds were observed to have difficulty in emerging.

In general, these greenhouse experiments with spring wheat confirmed the results from the field plantings of winter wheat, but a higher percentage of plants survived in the greenhouse than in the field.

In sand-box trials, in which conditions were undoubtedly more favorable than in the field experiments, Cronbach (8) reported a considerable advantage in germination of the clipped (half kernels) over that of the whole seed. In only one test did the writer observe the germination of fragments of seeds to be greater than that from whole seeds.

SUMMARY

Whole kernels and germ-end sections of half and one-third kernels of Dawson and Nittany winter wheats were planted in rows in the field at the Arlington Experiment Farm, Arlington, Va.

Whole kernels were superior to half and one-third kernels in germination and in subsequent plant survival, number of culms per plant (with one exception), total weight per plant, and grain yield per plant. Half kernels likewise were superior to one-third kernels except in one experiment involving too few one-third kernels.

Except in seed germination and in percentage of seeds producing mature plants, half kernels, the cut ends of which were capped with paraffin, were superior to unparaffined half kernels.

Whole, half, and one-third seeds planted in flats containing sterilized and unsterilized soil in the greenhouse in general confirmed the results of the field plantings, although the differences were not so marked owing in part to the crowded condition of the plants which prevented optimum development. In the unsterilized soil the plants

from one-third seeds appeared to be slightly injured by soil-borne organisms.

LITERATURE CITED

1. ANDRONESCU, D. I. Germination and further development of the embryo of *Zea mays* separated from the endosperm. Amer. Jour. Bot., 6:443–452. 1919.
2. ARNY, A. C., and GARBER, R. J. Variation and correlation in wheat, with special reference to weight of seeds planted. Jour. Agr. Res., 14:359–392. 1918.
3. BAYLES, B. B. Influence of environment during the maturation on the disease reaction and yield of wheat and barley. Jour. Agr. Res., 53:717–748. 1936.
4. BLOCISZEWSKI, T. Physiologische Untersuchungen über die Keimung und weitere Entwickelung einiger Samentheile bedecksamiger Pflanzen. Landw. Jahrb., 5:45–161. 1876.
5. BONNET, C. Recherches sur l'usage de feuilles dans les plantes et sur quelques autres sujets relatifs à l'histoire de la vegetation. Gottingen and Leyden. 1754.
6. BROWN, E. B. Effects of mutilating the seeds on the growth and productiveness of corn. U. S. D. A. Bul. 1011. 1922.
7. BROWN, H. T., and MORRIS, G. H. Researches in the germination of some of the Gramineae. Jour. Chem. Soc., 57:458–528. 1890.
8. CRONBACH, J. Conservation of seed wheat. Oakland City College [Indiana] Bul. 45. 1922.
9. DELASSUS. Influence de la suppression partielle des reserves de la graine sur le developpement de la plante. Compt. Rend. Acad. Sci., 153:1494–1497. 1911.
10. DUBARD, M., and URBAIN, J. A. De l'influence de l'albumen sur le developpement de l'embryon. Compt. Rend. Acad. Sci., 156:1086–1089. 1913.
11. KIDD, F., and WEST, C. Physiological pre-determination: The influence of the physiological condition of the seed upon the course of subsequent growth and upon the yield. I. The effects of soaking seeds in water. Ann. Appl. Biol., 5:1–10. 1918.
12. ———, ———. Physiological pre-determination: The influence of the physiological condition of the seed upon the course of subsequent growth and upon the yield. II–IV. Review of literature. Chapters I–III. Ann. Appl. Biol., 5:112–142; [157]–170 ;220–251. 1918.
13. KIESSELBACH, T. A., and HELM, C. A. Relation of size of seed and sprout value to the yield of small grain crops. Nebr. Agr. Exp. Sta. Res. Bul. 11. 1917.
14. SACHS, J. Zur Keimungsgeschichte der Gräser. Bot. Ztg., 20:145–151. 1862.
15. STINGL, G. Experimentelle Studie über die Ernährung von Pflanzen Embryonen. Flora, 97:308–331. 1907.
16. VAN TIEGHEM, P. Recherches physiologiques sur la germination. Ann. Sci. Nat., (5) 17:205–224. 1873.
17. WOLLNEY, E. Untersuchungen über die künstliche Beeinflussung der inneren Wachstumsursachen. VII. Der Einfluss des Vorquellens des Saatgutes auf die Entwickelung und Ertrage der Kulturpflanzen. Forsch. Geb. Agr.-Phys., 8:380–391. 1886.

NOTES

GERMINATION OF CARPET GRASS SEED

IN August, 1935, the late H. N. Vinall of the Division of Forage Crops and Diseases, Bureau of Plant Industry, requested that the Division of Seed Investigations, Bureau of Plant Industry, determine the germination requirements of seed of carpet grass (*Axonopus affinis* Chase). He also desired to know whether freshly harvested seed went through a dormant period, and the rate of loss of life of the seed under laboratory storage. Two samples of seed were furnished by Mr. Vinall for this study. One was from the 1934 crop (FC No. 13750, DSI No. 271304) and the other from the 1935 crop (FC No. 13749, DSI No. 271303). The heavy florets containing caryopses were separated with a laboratory blower, and the seed thus cleaned was used for germination studies. The 1934 crop sample contained approximately 73% heavy florets, and the 1935 crop sample approximately 40%.

Various temperature alternations were used. In presenting the results, the first temperature of a pair, e.g., 20° to 35° C, was maintained for approximately 17 hours daily and the second one for approximately 7 hours daily. In the condition "Room-35° C", the tests were placed in a north window of a room at approximately 20° from 4 p.m. until 9 a.m. and were kept in a chamber maintained at 35° for the remainder of the 24 hours.

For germination, the seeds were placed on paper towel discs in Petri dishes. The paper was moistened with tap water or with 0.2% potassium nitrate solution, as indicated. The results are averages of duplicate tests of 100 seeds each; half per cents were raised to the next higher per cent.

Germination tests made in September and October, 1935, under various conditions indicated 20° to 35°, and Room-35°, to be the most favorable conditions. However, when potassium nitrate was used to moisten the substratum, the final germination was equally good at 20° to 30° (with light at 30°), but the rate of germination was much slower. When water was used to moisten the substratum, the final germination at 20° to 30° was about 10% lower. The alternations 15° to 25° and 35° to 20° gave somewhat lower results. There was very little germination at 35° to 15°. Seed of the 1935 crop placed on a moist substratum at 35° for 7 days was made dormant so that, when transferred to 15° to 25°, the germination was much less than when tests were placed immediately at 15° to 25°. Chilling the moist seed for 7 days at 3°, 10°, or 15° before germination at 20° to 35° and 20° to 30° did not improve germination.

Tests were made of each sample at 20° to 35° and Room-35° with water and with potassium nitrate each month (with two exceptions) from September 1935 through December 1936. An additional test was made in October 1938. The averages of all tests for each of the above four conditions are shown in Table 1. There would seem to be no reason for suspecting superiority of any of the four methods. Experience with other samples indicates that occasional samples require exposure to light and the use of potassium nitrate for prompt and complete germination of the viable seed.

TABLE 1.—*Average germination of 15 successive tests of two samples of seed of carpet grass at four conditions.*

Seed crop	20°–35° C		Room—35° C		Average %
	Potassium nitrate %	Water %	Potassium nitrate %	Water %	
1934	54.28	55.71	54.14	55.14	54.817
1935	87.00	87.00	86.78	88.07	87.21

The average results of the 800 seeds tested in successive months are shown in Table 2. The results for September, 1935, represent only 400 seeds. The 1935 seed maintained its viabiltiy well over the entire 3-year period, although there is an indication of slight loss of viability after about 9 months. There is a suggestion from the results, but not definite proof, that there was a slight improvement in germination for several months after harvest.

TABLE 2.—*Average germination of two samples of carpet grass seed tested over a period of 3 years.*

Date of test	Percentage of germination	
	1934 crop seed	1935 crop seed
Sept. 11, 1935	67	90
Oct. 12, 1935	68	86
Nov. 12, 1935	67	88
Dec. 16, 1935	64	88
Jan. 15, 1936	64	89
Feb. 15, 1936	65	87
Mar. 18, 1936	60	90
May 16, 1936	57	91
June 20, 1936	63	93
July 14, 1936	59	85
Aug. 24, 1936	50	87
Oct. 2, 1936	53	86
Nov. 5, 1936	45	83
Dec. 16, 1936	46	84
Oct. 12, 1938	5	81

The 1934 seed when received approximately one year after harvest germinated much less than the 1935 seed after storage in the laboratory for 3 years. Also, the 1934 seed began to lose further in viability about 18 to 20 months after harvest and had lost its viability almost completely 3 years after it was received. These differences probably indicate injury to the 1934 seed by unfavorable storage conditions previous to its receipt in the laboratory, although the original germination of this sample is not known. Presumably, this previous storage was in a warehouse at the region of production in Mississippi.—EBEN H. TOOLE and VIVIAN KEARNS TOOLE, *Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

AGROBIOLOGIC SURVEY OF PERUVIAN CROPS

SOMETIME ago the writer suggested to various experiment stations in this country and abroad the desirability of comprehensive agrobiologic surveys of the yielding abilities of staple crops in their territories. Such surveys include the following:

1. Collection of regional statistics of average yields of staple crops, showing to what extent the average farmers of the region are exploiting the inherent yielding abilities of the species they are cultivating.

2. Collection of authentic data on exceptional yields of the same crops. Such data show what the species under cultivation are really capable of doing when, by accident or design, they have been provided with especially favorable conditions for growth. Particular search is made for "record" yields, i. e., the largest known yields per unit of land surface given by each kind of crop in the region. These record yields are considered to represent what the crop plants in question may be expected to yield if and when the farmers learn to duplicate the conditions under which the record crops were obtained. A record yield in one year may be exceeded in a following year; the latest record is presumed to represent the actually realizable yielding ability or "quantity of life" of that crop plant.

3. Analysis of *normally grown* crop plants to determine nitrogen percentage in the total dry substance (stalks, leaves, and fruit). Note is simultaneously taken of yield of total fresh substance and total dry substance. By "normally grown" is meant that the plants are cultivated in a non-toxic soil which is known to be supplied with all essential plant nutrients in fairly balanced proportions and with due regard to agrobiologic uniformity of stand. The nitrogen percentage, n, so obtained is inserted in the agrobiologic yield formula $358/n$; the quotient is the theoretical perultimate or maximum possible yield, in kilograms of dry substance per hectare, which a particular species is capable of giving in any event.

Such agrobiologic surveys indicate three things, *viz.*, (1) the present average level of agronomic efficiency of the region, (2) the attainable level of agronomic efficiency corresponding to the real capabilities of the crop plants as demonstrated in their record yields, and (3) the ultimate limit of the productivity of each species or variety deduced through the inverse yield/nitrogen law. The second item above sets a mark of efficiency for the farmers and the agronomists to aim at and is a reference point by which to measure agronomic success. Comparison of the record yield with the indicated perultimate yield will indicate the width of the margin within which future record yields may be enlarged, either by further improvement in cultural conditions or by further selecting.

To illustrate, I am permitted to quote some initial results of an agrobiologic survey of Peruvian agriculture which is being conducted by Professor José Carreras G. of the National College of Agriculture, La Molina, Lima, Peru.[1]

[1]Prof. Carreras' studies are currently published in *Agronomia* (Lima). See especially Vol. 3, No. 15.

SUGAR CANE

Six varieties of sugar cane were comparably grown at the La Molina Station. Observed and calculated data are given in Table 1. Measures are given in metric units.

TABLE 1.—*Agrobiologic data of six cane varieties.*

Variety	Millable cane, tons/ha.	N in whole dry substance %	Relative yield, POJ 2878 = 1	Millable cane %	Dry substance in whole plant %	Theoretical perultimate yield of millable cane, tons/ha.
	I	II	III	IV	V	VI
POJ 2878....	178.4	0.285	1.000	72	30	301.5
POJ 2714....	170.3	0.290	0.954	72	31	286.8
POJ 36 M...	168.7	0.290	0.945	68	31	270.4
BH 10(12)...	158.2	0.306	0.886	70	32	255.7
Cristalina...	145.5	0.318	0.815	66	30	247.5
Bourbon....	127.6	0.356	0.715	65	31	210.7

Comparison of the figures in columns I and II shows that the yields of millable cane are inversely proportional to the percentage of nitrogen in the dry substance of the whole plant. This conforms to the general inverse yield/nitrogen law that the smaller the normal nitrogen content of a plant species the greater is its potential yielding ability, or quantity of life. Nitrogen percentage determined on total dry substance is therefore a direct index of the potential vital vigor of sugar cane varieties. This is a rule given by direct observation and does not depend on any theory.

Application of the agrobiologic yield formula $358/n$ ranks these varieties in the same order as direct observation. Taking the data relating to POJ 2878, the perultimate yields (column VI) are calculated as follows: $358/0.00285 = 125{,}614$. The figure 125,614 is the perultimate yield of dry substance in kilograms per hectare. Dividing 125,614 by 0.30 (column V) and multiplying by 0.72 (column IV), we have $(125614/0.30) \times 0.72 = 301473$ kg, or 301.5 metric tons of millable stalks per hectare.

The figures in column VI of Table 1 represent the maximum expectation of yield if all growing conditions are furnished in perfect order. To see how nearly these perfect conditions have been approached, by accident or design, it remains to collate data on record yields. The record cane yields so far collected by Professor Carreras are given in Table 2. The yields here stated are commercial yields from areas greater than one *fanegada* (1 *fanegada* = 2.86 hectares = 7.06 acres).

Under experimental conditions at the La Molina Station the variety POJ 2714 has yielded up to 682 tons/fgd., corresponding to 82.3% of the perultimate. The data so far received from Professor Carreras do not specify a record yield for the Bourbon variety, but he states that in trials in the Lambayeque, Zaña, and Chicama valleys Bourbon consistently trails the other varieties.

All of the plots in this experiment were cultivated on June 10, at which time the corn was 1½ feet tall. Subsequent weeds were controlled by an additional cultivation late in June. Nitrogen stimulation in the treated plots was observed after the middle of June. Plants in the plots receiving the higher rates of cyanamid were darker green than were plants in the untreated plots.

The plots were harvested on October 21. Computed yields given in Table 1 are in terms of shelled corn at 15.5% moisture.

The need for the first two cultivations was eliminated by the pre-emergence treatment of the corn with cyanamid. Weeds were controlled most effectively by the application of 600 pounds of cyanamid per acre. The records indicate that the plots treated with granulated cyanamid at 300 pounds per acre and granulated and pulverized cyanamid at 600 pounds per acre yielded double that of the control plot.—DALE E. WOLF AND GILBERT H. ALGREN, *Department of Farm Crops, Rutgers University, New Brunswick, N. J.*

Book Review

GRAIN CROPS

By Harold K. Wilson. New York: McGraw-Hill Book Co., Inc. XI+384 pages, illus. 1948. $4.00.

THE author writes this text from a background of 18 years of teaching various phases of the production of grain crops. Presentation advances from the general to the particular, and principles are stressed. The selection of material is excellent, the development logical, the tabular material and especially the charts are exceptionally well chosen. Illustrations are adequate and refreshingly up to date.

The book starts with a brief chapter covering the significance of plants to life on this planet, the cycle of plant growth, effect of environment, and adaptation. This is followed by a short chapter on crop classification, which in turn leads to the distribution of grain crops, first for the world, and then for the United States. Selection of statistics is especially good in this section, supplemented by census maps showing the distribution within the United States.

The advantages of a good rotation and principles upon which it may be planned introduces the section on culture of the grain crops. This is followed by a consideration of soils for the various grains, seed cleaning and seed treatment, seedbed preparation, seeding, fertilizer and manure in the maintainance of fertility, cultivation, erosion control, harvesting, storing, and marketing. The chapter on weeds discusses the importance of these pests, classes of weeds, and weed prevention. Emphasis is placed on those most troublesome in grain crops. Control of weeds includes sections on tillage and cropping systems that are very satisfactory. Chemical control has developed so recently and so rapidly that it is not surprising to find little on the selective herbicides.

Grain crop diseases are discussed in general in a very satisfactory

chapter, which also includes sections on the more serious diseases of specific crops. A similar chapter is devoted to insects.

Presentation of this general material occupies eight chapters and the first 165 pages of the text. Chapters follow on wheat and rye, oats, barley, flax, rice, buckwheat, the millets, and soybeans. There are two chapters devoted to corn, and one each to sweet corn, popcorn, and sorghum. For each crop there is a discussion of the botany, varieties, special features of culture, marketing, etc., that are not covered in the earlier part of the book. Judicious repetition is used to clarify and round out these more detailed discussions.

Two general chapters complete the book. The first is on marketing of grain crops, including such topics as when a farmer should market his crop, the marketing processes, grain inspection, and an explanation of futures and hedging. The final chapter is on the improvement of grain crops, and in 28 pages the author indicates needs for improvement and methods by which new varieties, strains, or hybrids are developed.

Teachers should find this an excellent text. Occasional sections or statements may be too general, and sometimes one could wish for a little more data for comparison with nongrain crops. For example, the table showing amounts of plant nutrients removed in grain crops might well include one or two of the legumes which are indicated as desirable in planning rotations. By and large, however, the text is excellent, and in the opinion of the reviewer strikes a happy medium by presenting just enough well-selected tabular material to exemplify fully the principles.—C. A. LAMB.

Agronomic Affairs

ACCOMMODATIONS AVAILABLE FOR THE 1948 MEETING OF THE AMERICAN SOCIETY OF AGRONOMY AND SOIL SCIENCE SOCIETY OF AMERICA AT FORT COLLINS, COLORADO, AUGUST 24 TO 27

SINCE the meetings will be held during the peak of the Colorado tourist season, it is suggested that reservations be made as early as possible. To insure the holding of accommodations, it would be well to make an advance deposit of one day's rent. *Write directly to the lodging of your choice.* To those preferring to stay outside of Fort Collins, dependence on a personal automobile for transportation is recommended.

HOUSING UNITS IN FORT COLLINS

All accommodations listed are on the campus or within ten minutes driving time of the campus of Colorado A. & M. College.

CAMPUS, COLORADO A. & M.

For reservations write to Mr. Jack Nicol, Convention Housing, Colorado A. & M. College, Fort Collins, Colorado. Enclose one day's rent non-refundable.

Braiden Hall.—For couples, with or without children. New dormitory, double decker bunks. Towels not furnished. Showers. $1.50 per person per night.

South Hall.—For men only. Single rooms, double decker bunks. Towels not supplied. Converted Army Barracks. $1.00 per night per person, two men per room; $1.50 per night per person, one man per room if available.

HOTELS IN FORT COLLINS

Name	Address	Price per day
Armstrong Hotel	261 So. College Ave.	$1.75–$2.75
Northern Hotel	170 North College Ave.	$1.50–$5.00
Bennett Hotel	147 North College Ave.	$1.25–$2.50
Lincoln Hotel	206 South College Ave.	$1.50–$3.50

TOURIST COURTS IN FORT COLLINS

Name	Address	Price per day
All State Cottage Camp	1023 North College Ave.	$2.50–$4.50
Davey's Auto Court	1700 South College Ave.	$3.00–$5.00
Gaston's Cottage Court	1303 North College Ave.	$4.00–$6.00
Mountview Cottage Court	North of Ft. Collins	$3.00–$4.50
Overland Trail Auto Court	La Porte, Colorado	$2.50–$6.50
South Side Motel	1734 South College	$3.50
White Cottage Camp	1601 South College	$1.75–$4.25

All of the tourist courts have some cabins with cooking facilities, and reservations should be made in advance.

For additional information on housing at Loveland, Colo., within 14 miles of Fort Collins, and at Estes Park, 40 miles distant, write to the Housing Committee, Department of Agronomy, Colorado A. & M. College, Fort Collins, Colo.

FIELD TRIPS AT FORT COLLINS

DOCTOR Hans Jenny, President of the Soil Science Society of America, announces that arrangements are being made for field trips on Monday, August 23, and Saturday, August 28, for those attending the annual meeting of the Society at Fort Collins, Colo., August 24 to 27.

THE FIFTH INTERNATIONAL GRASSLAND CONGRESS

THE Fifth International Grassland Congress will be held at Noordwijk, Netherlands, June 22 to 26, 1949, and will be followed by a week's excursion covering grassland farming areas in the Netherlands.

The program of the Congress will be devoted to technical consideration of grassland problems under conditions comparable to those characterizing northwestern Europe. Technical papers will be delivered in five Sections of the Congress, under the following general topics: Soil and Manuring, Genetics (breeding and seed production of

grasses and clovers), Botanical Analysis of Grassland, Establishment, Management, and Utilization of Grassland, and Nutritive Value of Grass and Conservation of Fodder. A few more general papers will be presented at plenary sessions of the Congress.

Most of the papers will be by representatives of various European countries, but Congress officials have invited four papers by men from the United States.

Owing to anticipated difficulties in overcoming the effects of World War II on hotel and travel accommodations in the Netherlands, the officials have stated that limitations on attendance at the Congress must be imposed. The United States has been invited to send a small delegation, possibly 12 to 18 members. Consideration is being given the possibility of including within this limited number suitable representation of the Department of Agriculture and of State Experiment Stations and Extension Services in the Northeastern Quarter of the United States, since Congress officials have stated that preference should be shown this region as being more nearly comparable to conditions in Northwestern Europe. It is hoped that arrangements for a delegation from this country can be completed before November 1, 1948.

The Congress has made no announcement as to whether persons not included in delegations will be permitted to attend. It is assumed, in the absence of such an announcement, that persons other than those designated as members of delegations would have to make their own arrangements with the Congress.

The Secretary of the Congress is Dr. C. K. van Daalen, Bilthoven, Netherlands. He recently advised that the Congress fee, including the report of the Congress, will be 40 gilders per person. Hotel accommodations will cost from 9 to 13 gilders a day, and the excursion cost will be about 200 gilders. These costs would be in addition to the costs of transportation to and from the Congress, and subsistence while enroute. It is expected that all costs will be borne by the individual or the agency he represents.

Information about the Congress, as received, is being supplied by P. V. Cardon, Plant Industry Station, Beltsville, Maryland. He was Chairman of the United States delegation to the Fourth Congress in 1937, and has been kept advised of plans for the Fifth Congress.

NATIONAL ALFALFA IMPROVEMENT CONFERENCE

THE Nebraska Agricultural Experiment Station will be host to the National Alfalfa Improvement Conference at Lincoln on August 20 and 21. The meeting has been approved by the Regional Directors.

An interesting program has been arranged for discussions on alfalfa breeding and improvement, paying particular attention to requirements for the humid areas; alfalfa seed production as affected by harmful and beneficial insects; and information will be given on the development of new programs on the production and distribution of seed of new varieties and on the plan for preservation of the germ plasm of outstanding lines.

Field trips are planned to see the extensive alfalfa improvement work being carried on by H. O. Graumann at the Nebraska Station. The following hotels of Lincoln will accept reservations for the meeting: Lincoln Hotel, 147 No. 9th St.; Cornhusker Hotel, 301 So. 13th St.; Capital Hotel, 145 No. 11th St.; Milner Hotel, 119 So. 15th St.; Cornhusker Tourist Camp, 4200 O St. It is suggested that reservations be made early.—C. O. GRANDFIELD, *Chairman, National Alfalfa Improvement Conference, Kansas Agricultural Experiment Station, Manhattan, Kan.*

FOURTH EDITION
BIBLIOGRAPHY OF REFERENCES TO THE LITERATURE ON THE MINOR ELEMENTS

THE Chilean Nitrate Educational Bureau, Inc., announces publication of the fourth edition of the Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition.

The first edition of this Bibliography was published in August, 1935; the second, in November, 1936; and the third, in February, 1939. Subsequently, the 1st supplement was published in April, 1940; the 2nd, April, 1941; the 3rd, April, 1942; the 4th, June, 1943; the 5th, July, 1944; the 6th, November, 1945, and the 7th, July, 1947.

The fourth edition includes all material published in the third edition and the seven supplements thereto, together with some new material, making it complete as of June 30, 1947. There are 10,000 abstracts, which include 206 crops, 45 elements, and 4,463 authors. Complete indices are provided, i.e., author, element, botanical, and general nutrition. For further details write to the Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York 5, N. Y.

COMMITTEE ON EXTENSION PARTICIPATION

THE March issue of the JOURNAL (page 287) carries a list of names for the standing committee on Extension Participation which was organized prior to the development of the Division of Education. Since then, the new Division, under the chairmanship of Doctor H. E. Myers, has also developed a Divisional committee to consider the needs of Extension agronomists. It has been deemed advisable to combine these two committees into one for greater effectiveness and coordination of effort. The new committee on Extension Participation, therefore, is as follows:

P. M. Burson, *Chairman*

O. S. Fisher	S. R. Aldrich	J. P. Jones
C. S. Garrison	F. C. Burcalow	H. R. Lathrope
R. H. Tucker	H. B. Cheney	J. C. Lowery
C. P. Wayne	O. T. Coleman	M. D. Miller

DISTINGUISHED SERVICE AWARDS

AMONG the seven Distinguished Service Awards for 1948 made by the U. S. Dept. of Agriculture to employees recognized for outstanding contributions to science were presentations to Philip V. Cardon for exceptional leadership in the advancement of agricultural science and to Frederick D. Richey, a Fellow and former President of the Society, "For outstanding service in organizing and leading the cooperative corn-breeding program which gave hybrid corn to American agriculture". Mr. Richey is in charge of the Department's southern corn-breeding program with headquarters at the Tennessee Experiment Station, Knoxville. Mr. Cardon is Special Assistant to the Chief of the Bureau of Plant Industry, Soils, and Agricultural Engineering and is also serving as the Department's liaison officer and advisor to the Atomic Energy Commission.

A Superior Service award was also made to the Sugar Plant Field Station at Canal Point, Florida, for services above and beyond the call of duty in connection with salvaging most of the valuable world reference collection on sugarcane varieties, comprising 2,000 kinds of sugarcanes, that was nearly destroyed by being covered by 6 feet of water as a result of the hurricanes of 1947.

THE NATIONAL SOIL AND FERTILIZER RESEARCH COMMITTEE

SINCE publication in the May issue of this JOURNAL (pages 477–478) of the National Soil and Fertilizer Committee, certain revisions in the Committee have been made. The present Committee is as follows: H. C. Knoblauch, *Chairman;* F. W. Parker, *Secretary;* and F. E. Bear, W. R. Paden, C. O. Rost, D. W. Thorne, R. W. Cummings, W. T. McGeorge, M. L. Nichols, and K. D. Jacob.

A RANGE SOCIETY FORMED

A NEW society for professional range men, pasture specialists, graziers, ranchers, and range users held its first annual meeting at Salt Lake City, Utah, on January 30 and 31, 1948. The second annual meeting is to be at Denver, Colorado, in late January or early February, 1949.

The purposes and objectives of the Society are:

1. To foster advancement in the science and art of grazing land management.
2. To promote and support the maximum sustained use of forage and soil resources of the nation's grazing lands.
3. To stimulate discussion and understanding of practical range and pasture problems, and provide a medium for the exchange of ideas and facts among members and with allied workers.
4. To encourage professional improvement of its members.

Membership in this new range society is open to all persons engaged in or interested in range or pasture management. These liberal mem-

bership requirements reflect the broad training needed in the field of range management. The nearly 600 members represent the livestock industry, colleges and universities, federal, state, and other agencies.

This Society arose as a result of the desire of workers in the field for an organization where they could exchange ideas, discuss and agree upon procedures and practices, and, in general, further the maintenance and improvement of the grassland resource. They felt that the forage resources which cover over one-half the total land area of the United States need greater emphasis because of their importance as one of our basic natural resources.

The Society has as one of its goals the publication of a journal treating with range and pasture problems. It is hoped that the first issue of this journal will be released during 1948.

The present officers of the Society are, *President*, Joseph F. Pechanec, Portland, Ore.; *Vice President*, W. T. White, Portland, Ore.; *Secretary-Treasurer*, Harold F. Heady, College Station, Tex.; and *Council members*, F. G. Renner, Washington, D. C., George Stewart, Ogden, Utah, L. A. Stoddart, Logan, Utah, D. F. Costello, Fort Collins, Colo., B. W. Allred, Fort Worth, Tex., and Vernon A. Young, College Station, Tex.

NEWS ITEMS

DOCTOR E. V. STAKER, Associate Professor of Agronomy in the Chemurgy project in the University of Nebraska, Lincoln, Neb., joined the staff of General MacArthur's Far East Command in Tokyo in mid-March. He will have the responsibility of determining fertilizer needs and assisting with importation and distribution of fertilizers and general supervision of the soil and crop program in Japan, southern Korea, and Okinawa. Doctor Staker's assignment is for a minimum period of two years.

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DOCTOR RALPH W. CUMMINGS, Associate Director of the North Carolina Agricultural Experiment Station at Raleigh, N. C., recently made a five weeks' study of fertilizers as related to food production in the occupied areas of Germany and other European countries under auspices of the Department of National Defense.

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J. E. STECKEL assumed his duties at the Pennsylvania State College, State College, Pa., as Assistant Professor of Soil Technology on March 15, 1948. Professor J. W. White, Soil Chemist, will retire June 30, 1948, after 42 years of service.

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FORD M. MILAM, formerly Assistant in Soils and Crops Research, North Carolina State College, Raleigh, N. C., was elected Vice President of the Korean Agricultural Scientific Society at its annual meeting this spring. Mr. Milam has been serving since 1946 as a civilian employee of the War Department in directing the agricultural experiment stations of Korea.

C. J. WILLARD of Ohio State University and the Ohio Agricultural Experiment Station at Columbus, Ohio, has received three months leave to serve with the Mission on Science and Technology recently established by the State Department in the London Embassy. He left for Great Britain on April 24.

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DOCTOR LEON BERNSTEIN, formerly Research Associate (Assistant Professor) in Botany at the University of Chicago, has joined the staff of the U. S. Regional Salinity and Rubidoux Laboratories at Riverside, Calif. He will be associated with Dr. C. H. Wadleigh on problems of salt tolerance and the biochemical adjustments within plants as influenced by saline stresses.

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WILSON H. FOOTE, formally of the Plant Breeding Department, University of Minnesota, has accepted a position as Assistant Professor of Farm Crops and Assistant Agronomist at Oregon State College, Corvallis, Ore. Professor Foote will be engaged in forage crop breeding.

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SECRETARY OF THE INTERIOR J. A. KRUG has appointed Roscoe E. Bell of Boise, Idaho, coordinator of the western phosphate program of the Department of the Interior, to be Assistant Director of the Bureau of Land Management. The Bureau is charged with primary responsibility for the administration of Federal public land laws affecting the 775 million acres of Federal domain in the United States and Alaska.

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RUBEN M. HEERMANN has accepted a position as Assistant Agronomist with the Bureau of Plant Industry, Soils, and Agricultural Engineering and is located at Fargo, N. D. He is in charge of the Durum wheat breeding program in cooperation with the Department of Agronomy of the North Dakota Agricultural Experiment Station.

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GORDON HOFF has accepted a position with the New Mexico College of Agriculture as Agronomy Extension Specialist and began his duties April 1st. Mr. Hoff expects to receive his M.S. degree in agronomy from the University of Nebraska in June, 1948.

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JOHN S. WILLIAMS has been appointed Range Conservationist with the Forest Service in cooperation with the Coastal Plains Experiment Station, Tifton, Ga. Mr. Williams expects to receive his Ph.D. degree in June from the University of Nebraska.

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PROFESSOR ANDREW P. MAZURAK joined the staff of the Nebraska Agricultural Experiment Station, Lincoln, Neb., as Assistant Professor of Agronomy in the field of Soil Physics. Professor Mazurak

arrived March 1st from the University of California where he was Associate in Soil Physics. He takes the position held by Dr. Roger McHenry, who is now located at Washington State College, Pullman, Wash.

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DOCTOR L. K. WOOD, formerly Assistant Soil Scientist at the Oregon Agricultural Experiment Station, Corvallis, Ore., has been named Chemist and Spectroscopist in charge of minor elements research with soils, plants, and animals at the Kentucky Agricultural Experiment Station, Lexington, Ky. He succeeds Doctor J. S. McHargue who retired as Head of the Chemistry Department after serving in that capacity for 20 years.

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THE FOURTH INTERNATIONAL CONGRESS OF SOIL SCIENCE will be held July 24 to August 1, 1950, at Amsterdam, Netherlands. Every soil scientist interested in the Congress is requested to apply for further particulars and a preliminary application form to the Secretary of the Organizing Committee, Professor van Hallstraat, Groningen, Netherlands.

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E. L. ERICKSON, former Assistant Agronomist at the South Dakota Agricultural Experiment Station, has recently established a research, development, and manufacturing business known as the Ames Powercount Company. He has developed counting apparatus for packaging seed, seed blowers and seed cleaners for small lots, and work boards for seed separations of grasses and for starchy from waxy corn.

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DIMITRI NIKOLAEVICH PRIANISHNIKOV, a member of the Academy of Science of the USSR and for more than half a century a teacher and research worker in agricultural chemistry at the Timiriazev College of Agriculture in Moscow, died on May 4, 1948, at the age of 83 years. He remained active almost to the last. His latest work was a partial revision of an English translation of his book, "Nitrogen in the Life of Plants".

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PROFESSOR H. E. MYERS, Department of Agronomy, Kansas State College, Manhattan, Kansas, Chairman of the Committee on Resolutions of the American Society of Agronomy, requests that he be advised immediately of the death of any member of the Society in order that an appropriate statement may be included in the report of his committee at the annual meeting at Fort Collins, Colorado, in August.